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GEOPHYSICS.—*The figure of the earth from gravity observations.*[1]

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This is to be mainly a theoretical and historical treatment based on the work of three outstanding men, with some recent work of the Coast and Geodetic Survey in the preparation of certain tables coming in at the end, not as an intentional anti-climax but simply because it is latest in time.

By *figure* we may mean: (1) the general figure, the flattening of the oblate terrestrial spheroid; or we may mean (2) the figure in detail, that is, how much the geoid, or sea-level surface, deviates in this region and in that from the smooth mathematical spheroid of closest fit. The problem of the general figure of the earth will be discussed in connection with the names of two of the greatest contributors to its solution, Isaac Newton and Alexis Claude Clairaut; the problem of the detailed figure of the earth in connection with the name of George Gabriel Stokes.

NEWTON

Let us consider what was known about the figure of the earth at the time when the first edition of Newton's *Principia* appeared in 1686. Norwood about fifty years earlier had determined the length of a degree of the meridian by finding the distance between London and York; Picard in France had measured the meridional distance between Paris and Amiens and it was the length of a degree determined from Picard's work that Newton used in the first edition.[2] The

[1] Presented at the meeting of the Philosophical Society held February 29, 1936. Received June 19, 1936.

[2] The upper left-hand portrait of Fig. 1 comes ultimately from a volume in the Pepys Library at Cambridge, England. It is here reproduced by permission from Cajori's edition of the *Principia*, Sir Isaac Newton's *Mathematical principles of natural philosophy and his system of the world*, translated into English by Andrew Motte in 1729. The translation was revised, and supplied with a historical and explanatory appendix by Florian Cajori (published by the University of California Press in 1934). "In assigning, therefore, the date of this portrait to a period a few years on either side of 1691, we shall not perhaps be very wide of the truth. If this supposition be well-founded, this portrait may be considered as the most interesting of all the known portraits of our philosopher, as representing him at a time of life least remote from those memorable eighteen months which it cost him to produce the great work that immortalized his name." (Quoted on p. 627 of Cajori's edition from Edleston's *Correspondence of Sir Isaac Newton and Professor Cotes.*)

Fig. 1.—*Upper left:* Isaac Newton about 1691. *Upper right:* Isaac Newton in later life. *Lower left:* Alexis Claude Clairaut. *Lower right:* George Gabriel Stokes.

work of the Cassinis, father and son, which seemed to show a shortening of the degree of the latitude as the pole is approached and hence a prolate terrestrial ellipsoid instead of an oblate one, thus giving rise to prolonged controversy, was not yet completed. The third edi-

tion of the *Principia* appeared shortly before Newton's death[3] and after Cassini, the younger, had completed his work and announced that it showed the earth to be prolate. In this third edition Newton omitted the reference to the work of the Cassinis that he had made in the second edition, and simply hurdled over the difficulty, taking an average degree based on their arc extending across France from near the Spanish frontier to the English Channel.

With this approximate knowledge of its size Newton went on to consider its shape considered as a rotating fluid. The principles of hydrostatics were as yet undeveloped; the potential function had not been heard of; the differential and integral calculus was in a rudimentary state and Newton felt constrained to avoid in print the analytical methods that we now know him to have used for his own enlightenment.

He had obtained exact expressions for the attractions of certain bodies, especially for the attraction of figures of rotation on points in the axis. These are familiar when we penetrate the disguise of his form of statement. He also states the result for a point on the axis of an ellipsoid of revolution. How he performed the rather involved integration, or its equivalent, does not appear.

With this equipment he tackles the problem of the figure of the earth considered as a mass of rotating homogeneous fluid. In his diagram[4] PCQ, not ACB, is the polar axis. Imagine the mass solidified except for ACac and CQcq, which are small canals from the center to the equator and to the pole. A necessary condition for equilibrium is that the fluid in these canals shall balance at the center, allowing for the difference of attraction of the ellipsoidal mass in the two directions and for the centrifugal force along the canal CA. Bear in mind that there was no science of hydromechanics, no word or precise concept for the pressure of a fluid. Newton has no trouble with the centrifugal force; he has an exact expression for the attraction at Q, a point on the axis of rotation. The attraction at the point A on the equator bothers him somewhat. We now know that this attraction can be expressed by integration in terms of the elementary functions. Newton finds an ingenious approximation valid to the first power of the flattening.

Daniel Bernoulli, surely no mean mathematician, writing fifty years after Newton, finds an expression equivalent to Newton's, notes

[3] The upper right-hand portrait shows Newton, evidently in his later years as painted by Sir Godfrey Kneller. Reproduced from a picture furnished by the Library of Congress. Kneller died before Newton, so the portrait can not represent Newton toward the very end of his life, when the third edition appeared.

[4] Upper left-hand diagram of Fig. 2. Reproduced from Le Seur and Jacquier's edition of the *Principia*, Cologne, 1760. Book III, Prop. XX, Problem IV.

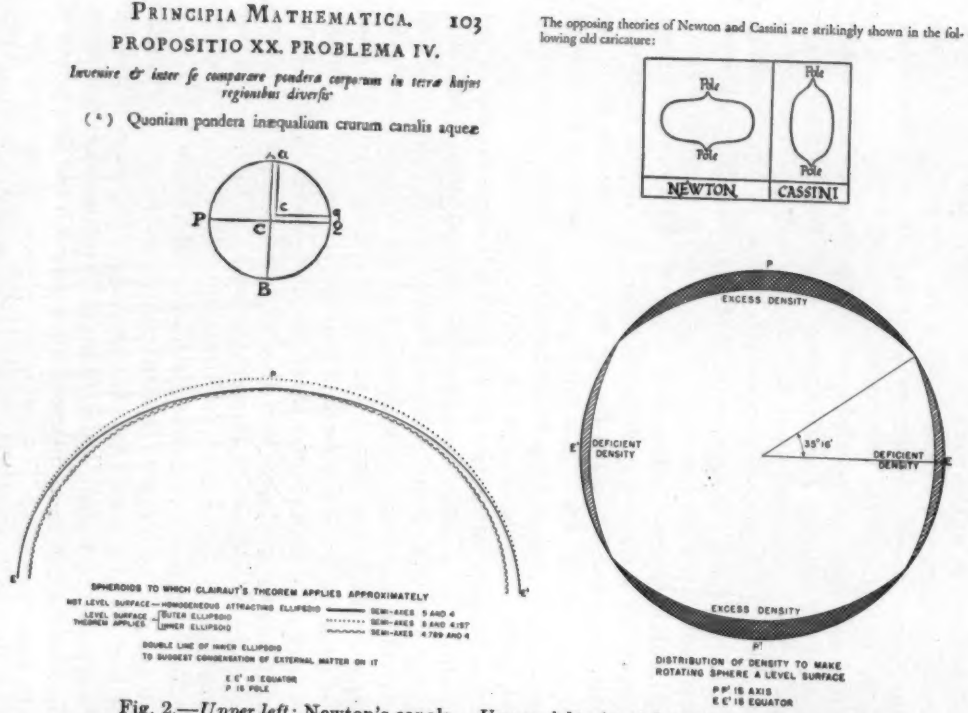

Fig. 2.—*Upper left:* Newton's canals. *Upper right:* An eighteenth-century caricature of the dispute concerning the figure of the earth. *Lower left:* Spheroids to which Clairaut's theorem applies. *Lower right:* The sphere as a level surface subject to Clairaut's theorem.

the fact and says: "As to this [Newton's] reasoning, perhaps only he himself could see his way through it, for this great man was able to see even through a veil, what another man scarcely discerns with a microscope."[5]

This particular passage is undoubtedly condensed and difficult, but Bernoulli to the contrary notwithstanding, with the aid of the *Principia* itself, Le Seur and Jacquier's useful commentary and Todhunter's[6] explanations it is possible to follow the train of Newton's thought. And Newton's comes out right in the end. If the earth were homogeneous, its flattening would be 1/230. This value is five-fourths of the ratio of the centrifugal force at the equator to gravity; this ratio is frequently denoted by m. The flattening of a homogeneous ellipsoid rotating with the speed of the earth is then $(5/4)m$. This is essentially the same result as would be reached with modern data by the help of modern mathematics. The earth is, of course, not quite so much flattened as this. Newton does not consider what would happen at points between the pole and the equator, nor does he show—what is true—that under the assumed conditions of homogeneity and fluidity the figure would be an exact ellipsoid.

For a test of his theory, Newton looked to pendulum observations, ignoring, as we have noted, measurements of meridional arcs. Astronomers going to the tropics had noticed that their clocks, carefully rated for some northern observatory, needed to have their pendulums shortened in order to keep time in the new location. Gravity, as he knew, would vary in this case between pole and equator as the square of the sine of the latitude. On this basis and with a flattening of 1/230, Newton prepared a table for various latitudes based on length of the second's pendulum in Paris[7] and compared it with the length found in the tropics.

For the first edition he had three observations; Cayenne in Guiana, St. Helena, and Goree near Cape Verde in Africa. For the third edition he had also Lisbon and Paraiba in Brazil, also various places in the *Spanish Main*. The places were near the coast and the reductions to sea level to make them comparable were perhaps small; Newton

[5] *Traité sur le flux et reflux de la mer*. Chapter II, Section VIII. Reproduced in Le Seur and Jacquier's edition of the *Principia*, Cologne, 1760, Vol. III, p. 146.

[6] *A history of the mathematical theories of attraction and of the figure of the earth*, Vol. I, pp. 9–17.

[7] This is given as 3 (Paris) feet 8.555 lines, equal to 99.382 cm. The modern value is 99.390 cm. The *hexapeda* of the table of lengths of degrees is the *toise*. Writers who use an ancient language, like the Latin, for modern purposes are obliged to use words "that would have made Quintilian stare and gasp." The toise was six Paris feet and was equal to 1.949 meters, or 6.394 U.S. feet. The Paris foot was divided into twelve inches and the inch into twelve lines. In the table of lengths of the seconds pendulum the inch does not appear, as it happens to be zero for all latitudes.

mentions the heights[8] of the mountains as possibly affecting the results, but applies no correction for this, although he does calculate the correction to the length of the Paris pendulum for the buoyancy of the air. The best that he can do for the temperature correction is to quote observations of Picard on the difference in length of an iron rod at freezing temperature and when heated and other observations

TABLE 1.—NEWTON'S TABLE OF LENGTHS OF THE SECOND'S PENDULUM AND MERIDIONAL ARCS OF 1 DEGREE.

Latitudo loci	Longitudo penduli		Mensura gradus uniús in meridiano hexapedæ
grad.	ped.	lin.	
0	3	7.468	56637
5	3	7.482	56642
10	3	7.526	56659
15	3	7.596	56687
20	3	7.692	56724
25	3	7.812	56769
30	3	7.948	56823
35	3	8.099	56882
40	3	8.261	56945
41	3	8.294	56958
42	3	8.327	56971
43	3	8.361	56984
44	3	8.394	56997
45	3	8.428	57010
46	3	8.461	57022
47	3	8.494	57035
48	3	8.528	57048
49	3	8.561	57061
50	3	8.594	57074
55	3	8.756	57137
60	3	8.907	57196
65	3	9.044	57250
70	3	9.162	57295
75	3	9.258	57332
80	3	9.329	57360
85	3	9.372	57377
90	3	9.387	57382

of de la Hire, and apparently of himself also, on the difference due to summer and winter temperatures; it is all as vague as that, although observations on the coefficient of expansion made with real thermometers not long after the appearance of the third edition of the *Principia* are noted by Le Seur and Jacquier. Newton discusses very sensibly the correction to be applied under working conditions and by correcting for temperature Richer's result, which he considers to

[8] To Newton's commentators, Fathers Le Seur and Jacquier, the effect of mountains and valleys appears as due solely to added or deficient matter. They do not see the necessity of reducing to a level surface, the idea of which was of course in the future. Their second edition (published in their lifetime) appeared after Clairaut had introduced the notion of level surfaces and Bouguer had corrected the values of gravity for elevation, but no mention of these ideas appears even in the second edition. Perhaps Newton was of the same mind with his commentators. His reference to mountains is very brief.

be based on the longest and most careful set of observations, he concludes that Richer's work bears out his theoretical flattening of 1/230. Hence the earth is, as he says, 17 miles, 3923.16/230, "higher" at the equator than at the poles, that is, the equatorial radius is 17 miles longer.

The observations with pendulum clocks other than Richer's give a greater excess of gravity at the pole over gravity[9] at the equator and hence, says Newton, the earth may be even *higher* at the equator than he had calculated for a homogeneous earth, that is, the equatorial radius is longer and the flattening greater than 1/230, instead of less, as we now know it to be.

This was a natural error. His commentators, Le Seur and Jacquier, accept it and the statement seems self-evident at first thought. Men of scientific standing fall into this trap once in a while even to this day. The flattening causes the difference in gravity between equator and pole. The greater the flattening, the greater this difference in gravity must be. But this is incorrect, as is proved by Clairaut's theorem, which at first seems like a paradox. The seeming paradox is easily explained and will be mentioned in connection with Clairaut. It is only fair to Newton, however, to add that in his third edition he suppressed one reference to this notion, as if his second thoughts seemed better than his first; but other passages implying the same idea remain unchanged from earlier editions.

Newton made one suggestion, however, to which no exception can be taken. He pointed out that greater density towards the center as compared with the surface would tend to increase the difference in gravity between pole and equator.

CLAIRAUT

Alex Claude Clairaut was born in Paris in 1713. His father was a teacher of mathematics and the son showed mathematical genius very early. When Clairaut was only twelve he read before the Paris Academy a memoir on four new curves discovered by him; when sixteen he published a memoir on space curves and when eighteen he was accepted as a member of the Paris Academy, although he was three years below the statutory age.[10]

Shortly afterwards he began working at problems in geodesy and

[9] Newton uses the *length of the seconds pendulum* as a measure of gravity, but *gravity* is a shorter expression and is therefore used here.

[10] The portrait of Clairaut (lower left-hand corner of Fig. 1) is reproduced from a German translation (with commentary by Jourdain and von Oettinger) of Clairaut's *Théorie de la figure de la terre*, etc., published as no. 189 of Ostwald's *Klassiker der exakten Wissenschaften*. The ultimate source of the portrait and the age of the subject are not given.

the equilibrium of fluids and publishing his results, but the work with which we are chiefly concerned did not appear till after his return from Lapland. He went there at the age of 23 as a member of a geodetic expedition headed by his friend, Maupertuis. The purpose of the expedition was to settle the question raised by the Cassinis on the basis of arc measurements in France, as to whether the earth was flattened or elongated at the poles. The work of the Cassinis was too inaccurate and covered too small a range of latitude to be conclusive, but their opinion that observation showed the earth to be prolate had for years divided the learned world into two opposing camps.[11] The meridional arc in Lapland settled the question, in fact it seemed to make the earth much flatter than it really is and Maupertuis was proclaimed by Voltaire "the flattener-out of the world and of Cassini." Voltaire, however, wrote also a poem in which he says of Maupertuis:

> You, choosing mid these frozen wastes to roam
> Confirmed what Newton found, who stayed at home.[12]

Maupertuis had confirmed Newton by observation. His follower, Chairaut, returning from the cold and mosquitoes of Lapland, took up the problem theoretically and partly confirmed Newton, partly corrected him. He published at the age of thirty his *Theory of the figure of the earth derived from the principles of hydrostatics*. The earlier chapters are largely devoted to mathematical discussions intended to refute the ideas of the Cartesian school of phisosophy, which believed in definite centers of attraction; this part is of comparatively little interest to us today.

In Chapter five Clairaut brings in the idea of a "level surface," which he calls "surface courbe de niveau." Maclaurin just one year before had spoken of level surfaces under exactly that name but Clairaut gave the condition for a level surface, namely in Cartesian coordinates that

$$Xdx+Ydy+Zdz$$

shall be a perfect differential, where X, Y, and Z are the components

[11] An eighteenth century caricature showing the views of the two opposing schools of thought regarding the figure of the earth is shown in the upper left-hand part of Fig. 2. The protuberance at the pole in both cases is doubtless the idea of the caricaturist, not that of either school of geodesy. Perhaps the caricaturist conceived the earth as revolving on a physical axle. Reproduced by permission from Cajori's edition of the *Principia* already referred to.

[12] "Vous avez confirmé dans ces lieux pleins d'ennui
Ce que Newton connut sans sortir de chez lui."
Voltaire. *Quatrième discours. De la modération en tout.* These verses do not appear in the first edition, which was more complimentary to Maupertuis. Perhaps another reason for changing the first edition was that it states that in *Lapland* the night is six months long (Où les rayons du jour sont six mois éclipsés).

of a force. The function of which this quantity is the differential, namely the potential, as we now call it, is not explicitly introduced, nor does the concept of level surface appear except in connection with the hydrostatic problem in hand. The introduction of the potential as an independent concept came about forty years later and the name was not introduced until 1828, when George Green chose it. Clairaut also states the test for deciding whether a given expression is a complete differential or not.

Clairaut determines the condition of equilibrium of a homogeneous spheroid accurate to powers of the flattening higher than the first, the point at which Newton stopped, proves that the spheroid is an exact ellipsoid and then goes on to discuss the attraction of heterogeneous spheroids; here his theorems are accurate only to the first power of the flattening. He considers both the case where the interior of the spheroid is in hydrostatic equilibrium and the case where it is not necessarily so. If we make no supposition about the interior but assume the outer surface is a level surface of small ellipticity under the influence of self-attraction and rotation—a surface like that of an ocean covering the whole earth—then we have Clairaut's theorem. This may be stated thus: Let g_p and g_e be gravity at the poles and equator of such a surface, f its ellipticity or flattening and let m be the ratio of the centrifugal force at the equator to gravity at the equator; then

$$\frac{g_p - g_e}{g_e} = \frac{5}{2}m - f.$$

For a given angular velocity and a given mass, m is nearly constant, so that the flattening, f, and the difference of gravity between pole and equator, $g_p - g_e$, vary in opposite directions because of the negative sign before f. When one increases the other decreases. Since the ellipticity is the cause of the difference in gravity, or *vice versa*, this seems paradoxical and it is the reverse of what Newton stated and his contemporaries accepted, at least when Newton was preparing the first two editions of his *Principia*. It is not clear even in his third edition that he had definitely changed his view.

One way of reconciling oneself to the seeming paradox is to remember that Clairaut's theorem applies to a level surface enveloping all attracting matter. Take a very flattened ellipsoid such as is shown in the lower left-hand corner of Fig. 2, which is not a figure of fluid equilibrium and therefore keeps its form because of its solidity. The theorem does not apply to the physical surface of such an ellipsoid.

It would apply to a level surface enveloping it, the ellipsoid indicated by the outer dotted line. It would apply also after a fashion to an inner level surface, if gravity were reduced to such a surface by the free-air reduction; that is, reduced to a smaller distance from the center in low latitudes, the distance through which the free-air reduction must be made to increase as the equator is approached. The theory behind the free-air reduction implies a condensation of matter external to the level surface upon that surface as a surface layer—that convenient mathematical fiction. The surface layer is indicated by doubling the dashed line representing the inner level surface. The isostatic reduction would give nearly the same result.

Again suppose the level surface to be a sphere in spite of the axial rotation. (See lower right-hand corner of Fig. 2.) In the formula of Clairaut's theorem

$$\frac{g_p - g_e}{g_e} = \frac{5}{2}m - f$$

put $f = 0$. Then the difference between equatorial and polar gravity is as large as possible—short of making f negative, that is, making the level surface prolate. But if we are absolutely determined that the sphere shall be a level surface in spite of the rotation, we must provide a suitable distribution of matter within it regardless of internal stresses. Such a distribution is suggested by the doubly cross-hatched portions of the diagram, intended to suggest the presence of matter of high density and the single hatched portions, intended to suggest matter of low density. This extra density near the poles and the deficient density near the equator account for the great difference in gravity between pole and equator, although the flattening is zero.

These two examples are merely an attempt to make Clairaut's theorem seem less of a paradox. Of course, they are not a proof.

It is quite clear that Clairaut made no assumption as to hydrostatic equilibrium or the lack of it within the spheroid to which his theorem applies. Nevertheless in later years the impression became widespread that he assumed internal fluidity. The agreement of the ellipticities deduced from pendulum experiments and Clairaut's theorem with those deduced from arc measurements was often cited as an argument in favor of internal fluidity. Stokes in giving a proof of Clairaut's theorem remarks that the theorem has been connected with the assumption of fluidity but that his (Stokes') proof does not require it. He adds that Laplace had proved a theorem analogous to

Clairaut's without assuming fluidity but says nothing of what Clairaut himself had proved.

This misconception may have arisen because Clairaut did prove another interesting theorem that does imply internal fluidity. It is a differential equation; for the geodesist it is *Clairaut's differential equation*. Needless to say it is not the Clairaut's differential equation of the mathematician, namely:

$$y = p\,x + f(p),$$

where $p = \frac{dy}{dx}$. To the geodesist Clairaut's differential equation is

$$\frac{d^2\epsilon}{dr^2} + \frac{2\rho r^2}{M}\frac{d\epsilon}{dr} + 2\left(\frac{\rho r}{M} - \frac{6}{r^2}\right)\epsilon = 0,$$

where $M = \int_0^r \rho\, x^2\, dx$. I shall not explain the notation nor discuss the equation in detail, nor mention some interesting modern developments in connection with it. It connects the ellipticities of the level surfaces within the earth with their radii and with the assumed law of density—on the hypothesis of hydrostatic equilibrium. With any physically probable law of density within the earth, the ellipticities of the level surface within the earth decrease toward the center.

STOKES

The theoretical basis for the study of the figure of the earth in detail by means of gravity methods was laid by George Gabriel Stokes, born in 1819. Stokes was the eldest of a famous trio of mathematical physicists; the others were James Clark Maxwell and William Thomson (Lord Kelvin).

Fig. 1 shows Stokes as an elderly man, almost seventy years of age.[13] He was only thirty when he made his great contribution to the study of the figure of the earth in detail, the "humps and hollows of the geoid," as we sometimes say with more picturesqueness than literal accuracy, for the word "hollows" suggests negative curvature, and this condition is rare or non-existent; the geoid for all practical purposes is everywhere convex.[14]

If we take a closed surface enclosing all attracting matter and assert that it is a level surface for that attracting matter, and if we

[13] From the *Illustrated London News* of 1887.

[14] A case of possible negative curvature of a level surface has been found in the Simplon tunnel by observations with the Eötvös torsion balance.

assign a value of gravity at any point on or outside the surface, then we can determine from the form of the level surface itself the value of gravity everywhere outside of it. The analytical and numerical work may be difficult or, for all practical purposes, impossible, but theoretically the thing is possible. Uniform rotation about a fixed axis adds but little to the difficulty. The international formula for gravity is based on the assumption that the surface of reference, which is at the same time a level surface, is an absolutely exact ellipsoid of revolution with a pre-assigned flattening, 1/297.

How about a sort of inverse problem? Given gravity on what we know to be a level surface enclosing all attracting matter, can we determine the form of the surface? If we have a fair previous idea of the form of the surface, the answer is: "yes, for all practical purposes." Stokes showed how it could be done in the case of the geoid, for which we have, as a fair approximation, a sphere or an ellipsoid.

We must in theory know gravity all over the geoid. When Stokes wrote his memoir *On the variation of gravity on the surface of the earth*[15] this must have seemed an assumption to be made chiefly for its speculative interest. Today we are still far from realizing this ideal, but with the method and apparatus of Vening Meinesz for determining gravity at sea, the possibility of realizing it exists, though it is premature to say that the realization is in sight.

Stokes dealt with gravity anomalies, the differences between observed gravity reduced to the geoid, g_0, and theoretical gravity according to some formula, γ_0, the formula implying a level surface, which is also a spheroid of reference. In $\Delta g = g_0 - \gamma_0$, g_0 and γ_0 refer to two different surfaces. Stokes saw this and allowed for the fact in his formulas. The same point comes up later in connection with Special Publication No. 199 of the Coast and Geodetic Survey. Suppose Δg expressed as a series of spherical harmonic terms

$$\Delta_g = G\ (u_2 + u_3 + u_4 + u_5 \cdots).$$

The u's are general surface spherical harmonics, functions of the latitude and longitude. G is a mean value of gravity over the earth. The degrees of the harmonic terms are indicated by the subscripts. The terms of degree zero can be made to disappear by choosing a proper mean value of gravity. Even if a term of degree zero were included, it would have no effect on the final result. The term of the first degree simply must not appear; if it does appear, there has been a mistake

[15] Transactions of the Cambridge Philosophical Society, 8: 672, or Mathematical and Physical Papers, 2: 131.

somewhere, and even if it did appear, the final result would be unchanged.

Then, says Stokes, it follows from this that if we call N the distance between the geoid and the spheroid of reference implied by the formula for theoretical gravity, then N is given by

$$N = a\left(\frac{u_2}{1}+\frac{u_3}{2}+\frac{u_4}{3}+\frac{u_5}{4}\cdots+\frac{u_n}{n-1}\cdots\right),$$

a being the radius of the sphere or the mean radius of the ellipsoid.

The quantity N, positive or negative as the case may be, gives us the "humps and hollows" of our geoid referred to the spheroid implied by the formula for γ_0.

It is easy to say that u_n represents a surface spherical harmonic of degree n, but when we remember that it is composed of $2n+1$ tesseral and zonal harmonics, each with a coefficient to be determined, we see that the work of determining even a few terms of the expansion is formidable. And when we reflect on the capricious variability of gravity anomalies, it becomes evident that the number of terms needed for even a very generalized expression of Δg would be overwhelming and the rapid convergence of the expression, supposing such an expression found, very much in doubt.

Stokes did not have in 1849 anything like the number of gravity anomalies that we now have, but he realized that his expansions in spherical harmonics would be practically unworkable for most purposes, that they could be merely stages on the way to something better. He does a few tricks with the series for N—Laplace had already done something of the sort—and transforms it into a surface integral

$$N = \frac{a}{4\pi G}\int \Delta g f(\psi)\, d\omega,$$

where $f(\psi) = 1+\operatorname{cosec}\frac{1}{2}\psi - 6\sin\frac{1}{2}\psi - 5\cos\psi - 3\cos\psi\log_e(\sin\frac{1}{2}\psi+\sin^2\frac{1}{2}\psi)$. This means in practice that we take a point, say A, for which N is desired, call ψ the angular distance on the earth from this point to some other point B, multiply $f(\psi)$ by the value of Δg for the element of solid angle ω for the portion of the earth surrounding B and that we thus evaluate our integral numerically by taking elements of solid angle and their corresponding anomalies over the entire earth. The terms in the expression for $f(\psi)$ have no individual physical meaning. They are simply the results of mathematical manipulation.

Stokes did not forget the possibility that the series from which was derived the integral that he proposed for actual calculation might not be convergent but he made no elaborate investigation. The validity of the transformation from series to integral was studied by others and finally in 1911 Pizetti[16] gave a proof that dispensed with the series altogether and derived the final result from Green's theorem. Poincaré had previously done about the same thing; it seems to have been an independent rediscovery of Stokes' formula, for Poincaré makes no mention of Stokes. (See article entitled *Les mesures de gravité et la géodésie*, Bulletin Astronomique. **18**: 7. 1901.) Pizetti also showed for the case of a spheroidal earth that the approximation is better than Stokes or Helmert felt justified in asserting it to be. In fact, it is amply good for present purposes.

Lately with the increasing possibility of the application of Stokes' theorem[17] to the practical problem of geodesy there has been an increasing interest in it and various proofs along the same general lines as that of Pizetti have recently been published. The theory of integral equations has also been brought into the discussion. Because these proofs dodge the thorny question of convergence they are preferable to Stokes' original proof but his arguments from spherical harmonics has the advantage of bringing out, as the other methods of proof do not, the relative importance of local and regional effects on the two elements that contribute to the gravity anomalies, namely: (1) the direct effect on gravity of the irregular distribution of matter; (2) the indirect effect due to this warping, because the observed values of gravity are reduced to the geoid, not to the spheroid of reference. They cannot be reduced to the latter because, until we have used Stokes' formula, we do not know where the spheroid is by tying it to anything observable.

[16] P. PIZETTI. *Sopra il calcolo teorico delle deviazione del geoide dell' ellissoide.* Atti delle Reale Accademia delle Scienze di Torino, **46**: 331, 1911. See also the following still more recent discussions among others: C. MINEO. *Sulla forma della terra.* Rendiconti del Circolo matematico di Palermo **51**: 1, 1927. N. IDELSON and N. MALKIN, *Die Stokessche Formel in der Geodäsie als Randwertaufgabe*, Gerlands Beiträge zur Geophysik, **29**: 156, 1931. Also N. MALKIN, *Über die Bestimmung der Figur der Erde.* Gerlands Beiträge zur Geophysik, **45**: 133. 1935. J. DE GRAAFF HUNTER, *The figure of the earth from gravity observations and the precision obtainable*, Philosophical Transactions of the Royal Society of London. **234**: Ser. A: 377. 1935.

[17] Stokes' theorem means to the geodesist what has just been described. As was the case with Clairaut, the discoverer's name has been also specially attached to another important theorem. To the mathematical physicist Stokes' theorem means that: The line integral taken around a closed curve s, of the tangential component of an analytic vector point function Q, is equal to the surface integral taken over any surface S, bounded by the curve, of the normal component of the curl of the vector, the direction of integration around the curve forming a right-handed screw rotation about the normals.

Stokes' theorem is the only means we have of studying the "humps and hollows" of the geoid at sea. On land we have other methods, and in certain respects more accurate ones. These are the deflections of the vertical, the differences between astronomical latitudes, longitudes and azimuths and the corresponding geodetic quantities. From these deflections, if they are closely enough spaced, we can build up the elevations of the geoid above our spheroid of reference. But the spheroids of reference in regions sundered by the intervening seas are in no ascertainable relation to one another, even though the assumed dimensions of these spheroids may be the same. Even though two originally separated pieces of triangulation may later be united and referred to a spheroid of the same dimensions and having the same position and orientation, there is no assurance that the center of this spheroid coincides with the center of gravity of the earth. But Stokes' formula automatically places the center of our spheroid of reference at the center of gravity of the earth. It will not give elevations and depressions of the geoid referred to a spheroid with any other center.

It is to be hoped, therefore, more observations of gravity will be made in the open sea in the near future. The sea covers nearly three-fourths of the surface of the earth and we cannot get a valid idea of the figure of the earth, even as a whole, much less in detail, nor of the structure of the crust until we have many more gravity observations at sea.

COAST AND GEODETIC SURVEY SPECIAL PUBLICATION NO. 199

We have passed in brief review the contributions of these leaders of thought to the problem of determining the figure of the earth from gravity observations. In closing let me refer briefly to a small contribution to the practical side of the problem, namely the computation of certain tables appearing in Special Publication No. 199 of the Coast and Geodetic Survey. Incidentally this publication contains more complete tables of Stokes' functions than have hitherto been published; these are in great part an extension of tables computed by Schumann.[18]

But the table of Stokes' functions was not the primary purpose of the publication. Its purpose is to provide means of estimating the indirect effect on gravity of irregular distribution of mass, such as we

[18] R. SCHUMANN, *Geoidabstände nach der Formel von Stokes bei schematischen Schwerebelegungen*, Sitzungsberichte der Kaiserlichen Akademie der Wissenschaften in Wien. Mathem.-naturw. Kl., **120**: Abt. IIA: 1655. 1911.

see in the relief of the earth's surface, and which we assume to be correlated with them when we adopt the assumption of isostatic compensation. The direct effect of such masses, their vertical attraction at a given point, was already taken care of by existing tables. But there is an indirect effect. It has been known since the time of Stokes that part of the gravity anomaly is due to the fact that observations are reduced to the geoid, not to the spheroid of reference. The same problem comes up in slightly different guise in connection with the isostatic reduction of gravity. When we move matter around, as we do in imagination in making an isostatic reduction, we change the form of the level surfaces. As a result of the hypothetical transfer of matter implied by the theory of isostasy, the actual geoid becomes what the Survey of India calls the "compensated geoid." If the assumed theory of isostasy were correct to the last detail, the compensated geoid would be the spheroid of reference. Isostatic reductions hitherto made have been incomplete, in that no allowance was made for the difference between the actual geoid and the compensated geoid, or spheroid.

The warping H, of the geoid due to any addition, subtraction or transfer of matter, isostatic or non-isostatic, may be put in the form

$$H = \frac{V}{g},$$

where V is the potential of the addition, subtraction or transfer and g is the acceleration of gravity. Certain precautions may be needed in using this equation but, even so, it is clear that what was needed was a table of potentials of certain masses or of quantities proportional to the potentials.

The obvious choice for the horizontal boundaries of these masses was the set of Hayford zones already used for isostatic reductions and recommended by the International Association of Geodesy for international adoption. As a step towards the isostatic tables, tables were computed adaptable to any distribution (within the limits set by the Hayford zones and reasonable ranges of thickness) whether isostatic or not. The tables and the explanation of how they were computed and how to use them, constitute Special Publication No. 199 of the Coast and Geodetic Survey.

CRYSTALLOGRAPHY.—*The crystal structure of krennerite.*[1] GEORGE TUNELL and C. J. KSANDA, Geophysical Laboratory, Carnegie Institution of Washington.

The rare telluride of gold and silver, krennerite, has been the subject of several morphological investigations. Faceted crystals of krennerite have been measured with the reflection goniometer by J. A. Krenner,[2] G. vom Rath,[3] A. Schrauf,[4] H. A. Miers,[5] and G. F. Herbert Smith.[6] They found the symmetry of the crystals to be that of the orthorhombic system. The values of the axial elements calculated by the various authors are given in Table 1.

TABLE 1.—AXIAL ELEMENTS OF KRENNERITE.

	a	*b*	*c*
VOM RATH	0.9407	1	0.5045
SCHRAUF	0.9396	1	0.5073
MIERS	0.9389	1	0.5059
SMITH	0.9369	1	0.5068

The investigations of calaverite by S. L. Penfield and W. E. Ford,[7] G. F. Herbert Smith,[8] and V. Goldschmidt, C. Palache, and M. Peacock[9] proved that krennerite and calaverite are quite different morphologically. The present writers have now established essential differences in crystal structure by the study of faceted crystals of krennerite and calaverite with the Weissenberg X-ray goniometer, the two-circle reflection goniometer, and the reflecting microscope.[10] Thus the statement of J. Murdoch[11] that "Krennerite is the same as calaverite" has been proved erroneous. Recently Borchert[12] concluded from studies of polished surfaces of calaverite and krennerite with the reflecting microscope, that calaverite is the high temperature modification and krennerite the low temperature modification of the same compound. He regards the faceted, apparently single, crystals

[1] Received October 30, 1936.
[2] J. A. KRENNER, Ann. f. Phys. und Chem., **1**: 636–640. 1877.
[3] G. VOM RATH, Zeit. f. Kryst. und Min., **1**: 614–617. 1877.
[4] A. SCHRAUF, Zeit. f. Kryst. und Min., **2**: 235–239. 1878.
[5] H. A. MIERS, Min. Mag., **9**: 184–186. 1890.
[6] G. F. HERBERT SMITH, Min. Mag., **13**: 264–267. 1903.
[7] S. L. PENFIELD and W. E. FORD, Amer. Jour. Sci., (4) **12**: 225–246. 1901.
[8] G. F. HERBERT SMITH, Min. Mag., **13**: 122–150. 1902.
[9] V. GOLDSCHMIDT, C. PALACHE, and M. PEACOCK, Neues Jahrbuch für Mineralogie, Geologie und Paläontologie, Beilage-Band **63**, Abt. A: 1–58. 1932.
[10] The authors are greatly indebted to Prof. L. C. Graton and Dr. E. B. Dane, Jr., of Harvard University for their kind assistance in the preparation and examination of the polished surfaces of krennerite and calaverite, and for the use of their polishing equipment and reflecting microscope.
[11] J. MURDOCH, Microscopical determination of the opaque minerals, p. 124, 1916.
[12] H. BORCHERT, Neues Jahrbuch für Mineralogie, Geologie und Paläontologie, Beilage-Band **61**, Abt. A: 106–116. 1930; also Beilage-Band **69**, Abt. A: 466–472. 1935.

of calaverite as paramorphs having the internal structure of krennerite (Borchert refers to the faceted, apparently single, crystals of calaverite as "Original-α-Calaverit" and to krennerite as "primärer β-Calaverit"). However, we have found that in each of these two minerals the structural axes (determined röntgenographically) and morphological axes (deduced from the study of the external form) exhibit such close correspondence that it is impossible to suppose that either one has passed through a polymorphic inversion. We[13] have proved elsewhere that the structural axes of calaverite coincide with its morphological *S*-axes in direction, and that the values of the axial elements determined röntgenographically by us agree very closely with the values of the morphological *S*-elements determined by Penfield and Ford, G. F. Herbert Smith, and Goldschmidt, Palache, and Peacock. In the present investigation we have found that the structural axes of krennerite coincide with its morphological axes in direction, and that the axial elements calculated from the dimensions of the structural unit cell, namely, $a:b:c=1.876:1:0.506$, agree well with the morphological axial elements if the value of a in the morphological elements be multiplied by 2.

Well developed faceted crystals of krennerite[14] from Cripple Creek, Colorado, previously measured by Dr. M. A. Peacock on the two-circle reflection goniometer, were used in our röntgenographic investigation. The dimensions of the structural unit cell were determined from Weissenberg photographs taken by means of Cu-radiation with the crystal rotating around the *a*-, *b*-, and *c*-axes (orientation of vom Rath), and found to be: $a_0=16.51$Å, $b_0=8.80$ Å, $c_0=4.45$ Å, all ± 0.03 Å. The unit cell contains 8 *molecules* of $AuTe_2$. An analysis by W. S. Myers[15] of faceted crystals of krennerite from Cripple Creek showed that a very small proportion of the gold is replaced by silver, which appears to be held in solid solution. The systematically missing spectra limit the space-groups possible for krennerite to three, namely, $Pmc-C_{2v}^2$, $Pma-C_{2v}^4$, and $Pmma-V_h^5$. From an analysis of the intensities of the diffraction spots on our Weissenberg negatives, from consideration of the close relationship between the structural lattices of krennerite and calaverite as determined by the Weissenberg study of single crystals, and from the close similarity of the powder photographs of the two minerals both as to positions and intensities of the diffraction lines, the atomic arrangement in krennerite must be one

[13] TUNELL AND KSANDA, this JOURNAL 26: 509–528. 1936.

[14] Kindly supplied by Prof. Charles Palache and Dr. M. A. Peacock of Harvard University, to whom the authors wish to express their appreciation.

[15] Amer. Jour. Sci., (4) 5: 376. 1898.

TABLE 2.—ARRANGEMENT OF THE 8 GOLD AND 16 TELLURIUM ATOMS IN THE UNIT CELL OF KRENNERITE.

Kind of Atom	Set of Equivalent Positions	Number of Equivalent Positions in Set	x	y	z
Au	(a)	2	0	0	0
Au	(c)	2	0.25	0.32	0.01
Au	(d)	4	0.12	0.67	0.50
Te	(c)	2	0.25	0.03	0.04
Te	(c)	2	0.25	0.63	0.04
Te	(d)	4	0.00	0.30	0.04
Te	(d)	4	0.13	0.37	0.50
Te	(d)	4	0.12	0.97	0.50

that is isomorphous with the space-group $Pma-C_{2v}^4$. The values of the 18 parameters were determined from the intensities[16] alone and are given in Table 2. The intensity calculations on which the determination of the atomic arrangement in krennerite rests, and the relationship between the crystal structures of krennerite and calaverite will be discussed in greater detail in a subsequent communication.

CRYSTALLOGRAPHY.—*The strange morphology of calaverite in relation to its internal properties.*[1] GEORGE TUNELL and C. J. KSANDA, Geophysical Laboratory, Carnegie Institution of Washington.

THE MORPHOLOGICAL PROBLEM OF CALAVERITE

The tiny, metallic, pale-yellowish crystals of calaverite are bounded by a strange array of faces, which has remained an enigma to crystallographers for more than 30 years. Exhaustive studies by several competent observers[2] established the angular relations of the faces of calaverite crystals, but it was found impossible to reconcile these relations with the law of simple rational indices as applied to a single crystal. This failure has led some investigators to question the general validity of the law of simple rational indices;[3] it has caused others[4]

[16] The authors are much indebted to Mrs. Ruth Philips Tunell for assistance in the calculation of the intensities.

[1] Received October 22, 1936.

[2] See V. GOLDSCHMIDT, C. PALACHE and M. PEACOCK, Neues Jahrbuch für Mineralogie, Geologie und Paläontologie, Beilage-Band 63, Abt. A: 50–52. 1932, for a careful account of the history of the investigation of calaverite; valuable data in this connection are also given by M. A. PEACOCK, American Mineralogist 17: 318. 1932.

[3] V. GOLDSCHMIDT, C. PALACHE and M. PEACOCK, op. cit., pp. 56–57, M. A. PEACOCK, op. cit., pp. 317–318.

[4] G. F. HERBERT SMITH, Mineralogical Magazine, 13: 122–150. 1902. H. BORCHERT, Neues Jahrbuch für Mineralogie, Geologie und Paläontologie, Beilage-Band 61, Abt. A: 106–116. 1930; also Beilage-Band 69, Abt. A: 466–472. 1935. J. D. H. DONNAY, Annales de la Société géologique de Belgique, 58: B222–230. 1935.

to attempt to interpret even those crystals of calaverite which appear to be simple, untwinned, individuals as some unfamiliar type of crystal intergrowth (ordinary types of twinning having been excluded for these apparently single crystals).

THE SYMMETRY OF CALAVERITE

In studying a number of excellent calaverite crystals[5] from Cripple Creek, Colorado, with the Weissenberg X-ray goniometer, as well as with the two-circle reflection goniometer and the reflecting microscope, we have obtained data that throw some new light on the problem of the morphology of calaverite. We[6] had previously proved that of the two alternatives for the symmetry of calaverite not excluded with certainty by Goldschmidt, Palache, and Peacock,[7] namely, orthorhombic and monoclinic, the first is incompatible with the observed intensities of the X-ray diffraction spots on our Weissenberg negatives. The planes, *hkl* and *hkl̄*, in general yield diffraction spots of very different intensity on these negatives. This would not be possible if calaverite belonged to the othorhombic system, irrespective of the space-group in the orthorhombic system with which it might be isomorphous. It is therefore certain that calaverite does not belong to the orthorhombic system.

THE STRUCTURAL LATTICE AND ITS CORRELATION WITH THE MORPHOLOGICAL *S*-LATTICE

The reciprocal lattice of calaverite was established by us by means of Weissenberg photographs taken with Cr-, Cu-, and Mo-radiation. The structural lattice has elements strictly analogous to the fundamental morphological elements of G. P. & P. (their *S*-elements). In our previous communication we[8] gave preliminary values of the unit cell dimensions, determined by purely röntgenographic measurements, as follows: $a_0 = 7.18$ Å, $b_0 = 4.40$ Å, $c_0 = 5.07$ Å, all ± 0.03 Å, $\beta = 90° \pm 30'$. We stated further that the correspondence between the positive and negative senses of our axes and those of G. P. & P. had not been established at that time but only the correspondence between the directions of our axes and the *S*-axes of G. P. & P. Subsequently we have been able to prove by the following methods that the positive senses of our three axes correspond to the positive senses of the

[5] Kindly furnished for the purpose by Dr. W. F. Foshag of the United States National Museum, to whom the authors' thanks are due.

[6] G. TUNELL and C. J. KSANDA, this JOURNAL, 25: 32–33. 1935.

[7] In the remainder of this paper in references to the joint work of GOLDSCHMIDT, PALACHE, and PEACOCK, the initials G. P. & P. are used for the sake of brevity.

[8] TUNELL and KSANDA, op. cit., p. 33.

three S-axes of G. P. & P. The faces of a small, well faceted crystal were identified by measurement on the two-circle reflection goniometer. Unlike many calaverite crystals this one gave quite satisfactory reflections in the prismatic[9] zone.[10] Eight forms were present in this zone of which seven were identified with the following forms of G. P. & P.: E, Λ:, a, c, A, ω:, K:. The two most prominent forms and those yielding the best signals were E and Λ:. The crystal was then mounted on the Weissenberg X-ray goniometer with the prismatic zone adjusted parallel to the rotation axis. The crystal was rotated about the axis of the prismatic zone until an easily recognizable plane, the ϕ and ρ angles of which were determined on the two-circle reflection goniometer, was brought into a position perpendicular to the X-ray beam. The establishment of the position of this plane in which it was perpendicular to the X-ray beam was accomplished by means of an auxiliary reflection goniometer, which can be attached to our Weissenberg X-ray goniometer in a precise manner such that the axis of the auxiliary goniometer is at right angles to the rotation axis of the Weissenberg X-ray goniometer carrying the crystal, and coincides with the center line of the X-ray beam (the Weissenberg X-ray goniometer being set so that the rotation axis carrying the crystal is perpendicular to the X-ray beam).[11] With the rotation axis of the Weissenberg goniometer (carrying the crystal) set and clamped so that the recognized plane of the crystal was perpendicular to the X-ray beam, the film-carriage was coupled to the rotation axis, and a spot was made on the film with a two or three second exposure of the direct beam. Given the zone of the crystal that is parallel with the rotation axis of the Weissenberg goniometer, and given the end of the crystal by which it is attached, there are of course two positions of the crystal in which the recognizable plane lying in the zone paral-

[9] The zone parallel to the b-axis (S-elements) of calaverite is prismatically dedeveloped and is referred to by G. P. & P. as the prismatic zone. Thus they state that "Die Zone prismatischer Entwicklung des Calaverit ist also die Querdomenzone. Aber wir können diese Zone kurz 'prismatische Zone' nennen, da sie prismatischen Charakter hat, obwohl sie nicht die Prismenzone ist." Op. cit., p. 8.

[10] This crystal was found in the interior of a larger, hollow calaverite crystal. This protected situation may have contributed to the perfection of growth and the excellent preservation of the small crystal.

[11] This X-ray goniometer was constructed in the Fysisk Institutt of Norges Tekniske Høiskole at Trondheim, Norway (cf. H. BRÆKKEN, Zeit. f. Krist., 81: 309–313. 1932, for a description of this instrument with photographs), and was modified by us so as to render it more readily available for the application of the equi-inclination technique, in accordance with the scheme of M. J. BUERGER (Zeit. f. Krist., 88: 358–359. 1934). The adjustments necessary with this modified apparatus were carried out by us by means of auxiliary apparatus constructed for the purpose in the shop of the Geophysical Laboratory. The source of radiation used in conjunction with this X-ray goniometer is a gas tube described by C. J. KSANDA (Rev. Sci. Instr., 3: 531–534. 1936).

lel with the rotation axis is perpendicular to the X-ray beam; at the time the direct beam spot was made a note was written down as to which of these two positions the crystal occupied. A shield was then inserted to prevent the direct beam from impinging on the film (the coupling of the film-carriage and rotation axis not being disturbed), the layer-line screen was inserted, and an equator Weissenberg photograph was made. When the film was removed from the film-carriage, a small scratch mark was made on the film in a particular corner and on the side of the film that was nearest the crystal; by means of this scratch mark the film could, in theory, be replaced on the film-carriage after development in the same position that it occupied during the exposure. Then, since the position of the film and carriage when the recognizable plane of the crystal was perpendicular to the X-ray beam was such that the direct beam spot on the film was precisely in front of the pin-hole, and since the sense of the translation of the film-carriage corresponding to a given character of rotation of the crystal (clockwise or counter-clockwise, the observer looking at the free, unattached end of the crystal) is always known from the construction of the instrument, therefore the position of the crystal, and in particular the position of each of its external faces (the symbols of which according to the indexing of G. P. & P. had been previously determined by measurements on the Goldschmidt two-circle reflection goniometer) when each diffraction spot was being formed on the Weissenberg negative, was uniquely and rigorously determined with respect to the rotation axis of the Weissenberg goniometer and the X-ray beam.[12] Thus the Miller indices corresponding to the *S*-axes of G. P. & P. of the plane producing each diffraction spot on the film were uniquely determined, and were found to be the same both numerically and in respect to all their positive and negative signs as those previously assumed provisionally by us[13] (before we found which of the angles between the *a*- and *c*-axes was greater than 90°).

In the foregoing discussion the correlation of the senses of our three axes with the senses of the three *S*-axes of G. P. & P. was rigorously established. Moreover this correlation did not depend in any way on

[12] The precise correlation of the external faces of a crystal with its structural (diffraction) planes is carried out by us as a routine by the above method, which, although its expression in words is cumbersome, is really simple and convenient in practice, and automatically prevents some possible confusions that might otherwise occur in structural work.

[13] In our preliminary report on the crystal structure of calaverite (this JOURNAL, 25: 32–33. 1935) we merely stated that $\beta = 90° \pm 30'$ and assumed positive senses of all our structural axes without reference to the morphology of the crystals. This did not affect the determination of the crystal structure but merely left to the future the determination of the relation between the positive and negative senses of our structural axes and the positive and negative senses of the *S*-axes of G. P. & P.

the recognition of the obtuse and acute angles between the normals to the forms *a* and *c*, either by G. P. & P. or by us, but on the contrary rested on the identification of the characteristic forms *E*, Λ:, *A*, ω:, *K*:. The designation of *A* and *E* as positive *S*-forms by G. P. & P. of course depended on their measurements of the angle between the normals to the forms *a* and *c;* the average of their measurements of this angle was reported to be 89°54′; the value calculated by G. P. & P. is 89°52′.[14] Concerning the angle between the normals to the forms *a* and *c* they[15] wrote: "Dieser Winkel ist so nahe an 90°, dass die Frage, ob der Neigungswinkel von 90° verschieden ist, nicht aus den Messungen entschieden werden kann." The angle between the normals to the forms *a* and *c* determined previously by Penfield and Ford[16] was 89°47½′ and that determined by G. F. Herbert Smith[17] was 89°50′. The same forms were found to lie with their normals in the acute angle between the normals to the forms *a* and *c* in all these investigations. With the reflection goniometer we had measured the angle between the normals to the forms *a* and *c* of the crystal mentioned in the preceding paragraph to be 89°56′, and we had found the same forms to lie with their normals in the acute angle between the normals to the forms *a* and *c* as G. P. & P. Although any single measurement of the angle between the normals to the forms *a* and *c* with the reflection goniometer might be in error by an amount as great as the difference from 90° of the angle between the normals to the forms *a* and *c*, it is extremely improbable that previous investigators would all have obtained a value greater than 90° for the angle that is really less than 90°, and all have reached a wrong conclusion as to which forms are positive and which are negative. Moreover in our later studies with the Weissenberg goniometer on the same crystal we were able to prove by röntgenographic measurements alone that the angle between the normals to the planes 100 and 001 differs from 90° a little more than the probable experimental error—from our röntgenographic measurements this angle equals 89°47′—and the external faces found to lie with their normals in the acute angle between the normals to 100 and 001 determined röntgenographically were the same ones found to lie with their normals in the acute angle between the normals to 100 and 001 determined with the reflection goniometer. Thus our röntgenographic studies afford a definite confirmation of the conclusion of Penfield and Ford, G. F. Herbert Smith, and G. P. & P.,

[14] G. P. & P., op. cit., p. 29.
[15] G. P. & P., op. cit., p. 5.
[16] S. L. PENFIELD and W. E. FORD, Amer. Jour. Sci., (4) 12: 227. 1901.
[17] Op. cit., p. 135.

based on studies with the reflection goniometer, as to which of the forms are positive and which are negative.

Since the axial elements computed from the unit cell dimensions determined by purely röntgenographic measurements agree with those previously determined by Penfield and Ford,[18] G. F. Herbert Smith,[19] and G. P. & P.[20] very closely, it might be assumed without further investigation that no polymorphic inversion has taken place in the calaverite crystals and that the structural planes lie parallel with the analogous crystal faces. However, in view of the various hypotheses that have been suggested by different authors to account for some of the peculiarities of calaverite, and in view of the fact that its morphological development appears to violate the fundamental crystallographic law of simple, rational indices, it is desirable to establish the relationship between the crystal faces and structural planes as fully and exactly as possible by measurement and observation alone. The procedure described above for the correlation of the external faces of a crystal with its structural (diffraction) planes by means of a spot on the Weissenberg negative produced by a short exposure of the direct X-ray beam when the faces of the crystal occupied a defined position with respect to the rotation axis of the Weissenberg goniometer and the X-ray beam, permitted us to prove that the *S*-axes defined by the morphology of the crystal are parallel with the structural axes of the same crystal (within the limits of error of our measurement of the angle between an external face and a structural plane, which are $\pm 1°$).[21]

[18] Op. cit., p. 227. [19] Op. cit., p. 135.
[20] G. P. & P., op. cit., p. 6. M. A. Peacock, op. cit., p. 325.
[21] Little need has previously arisen for a measurement of the angle between an external face of a crystal and a structural (diffraction) plane of the same crystal, and it is probably desirable that we explain just what is meant by such a measurement. By the angle between an external crystal face and a structural (diffraction) plane of the same crystal we mean the angle through which the crystal was turned from the position in which the external face occupied an arbitrary position with respect to the rotation axis of the Weissenberg goniometer and the X-ray beam, as determined by means of the auxiliary reflection goniometer, until the structural (diffraction) plane occupied the same arbitrary position, as determined by the positions of the diffraction spots from the structural plane in relation to the shadow of the crystal in the central portion of the spot made by a short exposure of the direct X-ray beam when the external crystal face occupied the arbitrary position at the beginning of the measurement. The determination of the angle between the normals to the planes 100 and 001 by purely röntgenographic measurements was more accurate than such a measurement of the angle between an external face of the crystal and a structural (diffraction) plane, as the former is not subject to certain factors of error that affect the latter: the former depends merely on the relative positions of the diffraction spots of the two structural planes 100 and 001 on a single Weissenberg negative, whereas the latter depends on the relative positions of the diffraction spots from one structural plane with respect to the shadow of the crystal in the central portion of the spot made by the short exposure of the direct X-ray beam when the external face of the crystal occupied a defined position with respect to the rotation axis of the Weissenberg goniometer and the X-ray beam.

THE CRYSTAL STRUCTURE OF CALAVERITE

The crystal structure of calaverite has already been described by us[22] in a preliminary communication. The arrangement of the two gold and the four tellurium atoms in the unit cell is rather simple; it can be realized in either the space-group $C2/m - C_{2h}^3$, or the space-group $C2 - C_2^3$, and the parameters have been evaluated on the basis of both alternatives and found to be the same. Besides the gold and tellurium required by the formula $AuTe_2$, calaverite contains a small amount of silver, ranging, in the analyses of crystallographically studied material, from 0.40 to 3.23 per cent.[23] This silver appears to be held in solid solution, but the exact mode of disposition of the silver atoms in the structure requires further study in the search for a more complete explanation of the relation between the structure and morphology of calaverite.

PREVIOUS MORPHOLOGICAL INVESTIGATIONS OF CALAVERITE AND THE PECULIARITIES IN MORPHOLOGY THEREBY FOUND TO BE CHARACTERISTIC OF CALAVERITE CRYSTALS

In their investigation, which first established the symmetry and axial elements of calaverite, Penfield and Ford[24] noted that the angles between certain faces of calaverite agreed very closely with the angles between corresponding faces of sylvanite. This relation is shown by Table 1 from Penfield and Ford.[25,26]

TABLE 1.—A COMPARISON OF CALAVERITE AND SYLVANITE FROM PENFIELD AND FORD.

Calaverite	Sylvanite
$m \wedge m'$, $110 \wedge \bar{1}10 = 63°\ 1'$*	$110 \wedge \bar{1}10 = 62°56'$
$p \wedge p$ $111 \wedge \bar{1}1\bar{1} = 93\ 49$	$111 \wedge \bar{1}1\bar{1} = 94\ 30$
$m \wedge p$ $110 \wedge 111 = 36\ 38$*	$110 \wedge 111 = 37\ 3$
$m' \wedge p$ $\bar{1}10 \wedge 111 = 68\ 45$*	

From the measurements marked by asterisks Penfield and Ford calculated the values of Table 2 for the axial elements of calaverite, which they compared with the axial elements of sylvanite determined by Schrauf.[27]

[22] TUNELL and KSANDA, op. cit., p. 33.
[23] PENFIELD and FORD, op. cit., p. 246. G. F. HERBERT SMITH, op. cit., p. 149.
[24] Op. cit., p. 227.
[25] Op. cit., p. 227.
[26] The faces designated m and p by Penfield and Ford were designated with the same letters by G. P. & P.
[27] A. SCHRAUF, Zeit. f. Kryst. u. Min., 2: 211. 1878.

TABLE 2.—COMPARISON OF AXIAL ELEMENTS OF CALAVERITE AND SYLVANITE.

	a	b	c	β
Calaverite (Penfield and Ford)	1.6313	1	1.1449	90°12½′
Sylvanite (Schrauf)	1.6339	1	1.1265	90°25′

The close similarity of the two sets of elements was considered by Penfield and Ford as evidence in favor of their choice of the elements of calaverite.

G. P. & P.[28] later selected polar elements analogous to the linear elements of Penfield and Ford as the fundamental polar elements of calaverite. These polar elements, namely, $p_0:q_0:r_0 = 0.7051:1.1492:1$, $\mu = 89°52'$, G. P. & P. designate as the polar S-elements. With respect to the S-elements, the three established twinning laws of calaverite are as follows. "1. The twinning and composition plane is $V(101)$; the axes of the prismatically developed zones of the two individuals are parallel. 2. The twinning and composition plane is $\beta(310)$; the axes of the prismatically developed zones of the two individuals intersect at 122°58′. 3. The twinning and composition plane is $p(111)$; the axes of the prismatically developed zones of the two individuals intersect at 93°40′."[29] Concerning these twinning laws G. P. & P.[30] conclude that: "Die Zwillingsebenen des Calaverit sind alle einfache S-Flächen. Dies spricht für die grundlegende Wichtigkeit dieser Elemente. Das gemeinste Gesetz des Calaverit, $V = \infty\,(110)\,S(M_2) = 10(101)S(M_1)$,[31] ist auch das Hauptzwillingsgesetz des Sylvanit [Zwillingsebene $m = 10(101)M_1$]." Furthermore Donnay[32] has shown that these three twinning laws are readily explained by the Bravais-Mallard-Friedel theory of twinning if the S-lattice is taken as the morphological lattice of calaverite. The index and the obliquity of each of these three kinds of twins are small and the relative values of these quantities lead to an expectation concerning the frequency of occurrence which is in agreement with the data of observation—"macle $V(101)$, indice 3, obliquité 0°25′; la plus probable; macle

[28] Op. cit., p. 6.
[29] M. A. Peacock, op. cit., p. 325.
[30] Op. cit., p. 20.
[31] The symbol $\infty\,(110)S(M_2)$ of the face V here indicates that when the crystal is projected on a plane perpendicular to the symmetry axis (b-axis), the Goldschmidt symbol of the face V is ∞ referred to the S-axes in this orientation (the M_2-orientation); the Miller indices (110) are here given in the order, *cab*, corresponding to the M_2-orientation of the crystal. Similarly the symbol $10(101)S(M_1)$ of the face V refers to the normal or M_1-orientation of the crystal with the c-axis vertical and the plane of the gnomonic projection drawn perpendicular to the c-axis; 10 is the Goldschmidt symbol of the face V in this orientation, and (101) is the Miller symbol with the indices in the usual order, *abc*.—G. T. and C. J. K.
[32] Op. cit., p. B228.

$\beta(310)$; indice 2, obliquité 4° 16′; moins probable; macle $p(111)$, indice 3, obliquité 5°11′; la moins probable."

Thus the fundamental rôle of the *S*-elements in the crystallography of calaverite has emerged both from observations with the reflection goniometer and from analysis of photographs taken with the Weissenberg X-ray goniometer. However, certain features in the morphology and in the X-ray diffraction patterns of calaverite are not explained by the *S*-lattice, and attempts to elucidate them have resulted in numerous hypotheses, which will be discussed briefly in this paper, after these unusual features have been described.

The peculiarity in the morphology of calaverite, which has been observed by all investigators who have studied it with the reflection goniometer, is that only a minority of its forms receive simple indices when referred to the *S*-elements. Thus of the 92 established forms only 12 (of which, however, 6 occur among the 11 most frequently observed forms as listed by G. P. & P.[33]) are simple *S*-forms. One of the most frequently occurring forms is that designated *C* by G. P. &. P., which consists of a pair of faces on each termination, each of these faces making an angle of 7°53′ with the clinopinacoid, *b*. The two face-poles of the form *C* that are situated near the projection of the positive end of the *b*-axis appear to lie each at the intersection of 2 zones through frequently occurring *S*-forms; one of the face-poles lies at the intersection of a zone through the *S*-faces 304 and 111 with a zone through the *S*-faces 801 and 110; the other face-pole lies at the intersection of a zone through the *S*-faces $\bar{3}0\bar{4}$ and $\bar{1}1\bar{1}$ with a zone through the *S*-faces $\bar{8}0\bar{1}$ and $\bar{1}10$. Thus, according to G. P. & P., the form *C*, considered as an *S*-form, has the rational but complicated symbol, $(\bar{5}.29.3)$. In the gnomonic projection of calaverite constructed on the plane perpendicular to the symmetry axis (*b*-axis), the 80 complex forms lie partly in zones connecting the 2 "singular nodes" *C*, with the *S*-forms *p* and *w*, and the remainder in two families of zones parallel with the *CS* zones $[Cp]$ and $[Cw]$.[34,35] All the forms of calaverite except 12 *S*-forms receive symbols of great complexity on the *S*-elements. However, it had been found by Smith, that the complex faces possess zonal relations, and that in the various zones even the complex faces are almost invariably distributed in accordance with the law of simple, anharmonic ratios. The mutual relations of the complex faces were found to be such that, by constructing other sets

[33] Op. cit., Table 31, p. 48.
[34] G. P. & P., op. cit., p. 21.
[35] All letters used to designate faces of calaverite crystals in this paper are those of G. P. & P. unless otherwise noted.

of axes than those used by Penfield and Ford, and referring one group of faces to one set of axes and other groups to other sets of axes, Smith was able to assign relatively simple indices to most of the forms. He[36] concluded that "five distinct lattices may be traced in calaverite, which are incongruent but not independent. The prism zone is common to all." These results of Smith were extended by G. P. & P., who found that, besides the *S*-elements, 4 sets of *C*-elements are needed, 3 of the 4 sets of *C*-elements being repeated by the symmetry axis (*b*-axis) to give a total of 7 sets of *C*-elements, and a grand total of 8 sets of elements, including the *S*-elements. Of these, all except the *S*- and C_0-elements are triclinic. However, even with the 8 sets of elements "There remain a number of prismatic forms (CC_2-forms) which lie in zone with the base *C* (001) of the C_1-elements and with nodes of the incongruous C_2-elements. These forms are therefore incongruous to both groups of elements and cannot be given simple symbols."[37] In other words even with 8 sets of elements there remain faces, some of them important[38] ones, that cannot be given simple indices. For this reason Peacock[39] concluded that: "It is of no value to express these groups of elements [i.e. the polar *C*-elements.—G. T. and C. J. K.] as triclinic linear elements. The linear constants do not show the close relations which exist between the several groups of polar elements, and they would imply a triclinic interpretation of calaverite which we reject." G. P. & P. found that, not only are the angular relations in the complex zones such that the law of simple, anharmonic ratios is satisfied, but in addition the distribution of the faces in the complex zones appears to conform closely with Goldschmidt's "law of complication." In their view "The singular node pair *C* was the key to the calaverite puzzle. When it was recognized that the node *C* with its complicated symbol was yet the simplest node, namely the node of origin (0), in each zone containing *C*, and that every zone of calaverite gave a more or less complete N_3 complication series[40] without extra terms, it was apparent that calaverite conformed strictly to the Law of Complication as it was formulated many years ago."[41] They also concluded that "no admissible assumptions of twinned or heterogeneous structure will serve to bring this

[36] G. F. Herbert Smith, op. cit., p. 140.
[37] M. A. Peacock, op. cit., p. 327.
[38] So regarded by G. P. & P. (op. cit., p. 52), also by the present writers.
[39] Op. cit., p. 327.
[40] A clear statement of what is meant by an N_3 complication series was given by Peacock on pages 319–320 of the article from which this quotation is drawn.
[41] M. A. Peacock, op. cit., p. 323.

crystal species within the Law of Rationality in its generally accepted form."[42]

ADVENTIVE DIFFRACTION SPOTS AND THEIR RELATION TO THE COMPLEX FACES OF CALAVERITE CRYSTALS

In our röntgenographic investigation of calaverite we of course expected to obtain information as to whether or not the morphological *C*-lattices have structural counterparts as well as the morphological *S*-lattice. From our rotation and Weissenberg photographs we find only one structural lattice in calaverite. However, in addition to the diffraction spots on our rotation and Weissenberg negatives corresponding to planes of the structural lattice (analogous to the morphological *S*-lattice), there are present certain other diffraction spots (of weak intensity but nevertheless quite distinct) which we term adventive diffraction spots. These adventive diffraction spots cannot be ascribed to planes of the structural lattice; if it were assumed that the adventive diffraction spots are produced by planes belonging to the structural lattice, it would be necessary to conclude that the unit cell of calaverite contains not 2 *molecules* of $AuTe_2$ but a number many times greater, and in this case there would be an enormous number of planes that might give diffraction effects on our films, but from which no diffraction effects are present. Thus the assumption of a larger unit cell than that determined by Tunell and Ksanda[43] is incompatible with the observed planar spacings. There are other equally cogent reasons for stating that the adventive diffraction spots are not produced by planes of the structural lattice. Thus, although no crystal has been found by us that does not yield some adventive diffraction spots, nevertheless a large proportion of the adventive spots present on the rotation and Weissenberg films of one calaverite crystal are missing on the corresponding films of another calaverite crystal, whereas, of course, the diffraction spots from the planes of the structural lattice are present on the films of all the calaverite crystals investigated, and spots from analogous structural planes of different crystals have approximately the same intensities. On the first layer-line of one calaverite crystal (rotation around the *b*-axis) there is a large number of adventive diffraction spots and on the equator of the same crystal (rotation around the same axis) there are a few; on the first layer-line of another crystal (rotation around the same axis) there are only 2 adventive diffrac-

[42] M. A. PEACOCK, op. cit., p. 318.
[43] Op. cit., p. 33.

tion spots, and on the equator (rotation around the same axis) of this crystal there is none. Moreover we have made a considerable number of powder photographs of calaverite crystals with Cu-, Fe-, and Cr-radiation and have found on them no adventive lines but only lines corresponding to planes of the structural lattice. This result is not surprising in view of the fact that the adventive spots on the X-ray photographs of single crystals are of relatively weak intensity. On the rotation photographs taken around the *b*-axis and Weissenberg photographs taken around the *b*- and *a*-axes it can be seen that the adventive spots are mostly confined to the layer-lines of the *b*-axis photographs although a few occur between them. From this it follows that if the diffraction planes giving rise to the adventive diffraction spots were indexed on the structural axes (analogous to the morphological *S*-axes) most of these planes would have small whole numbers as values of *k* in their symbol, *hkl*. On 180°-oscillation and Weissenberg photographs taken around the *a*-axis it appears that most of the adventive spots occur between the layer-lines of the *a*-axis photographs; thus if the diffraction planes giving rise to the adventive diffraction spots were indexed on the structural axes, most of these planes would not have whole numbers as values of *h* in their symbol, *hkl*. In the drawings of the reciprocal lattice layers constructed by the method of Schneider[44] it is observed that the points corresponding to the adventive spots nearly all satisfy the requirements of the two-fold symmetry axis; however, the adventive diffraction spots are almost all weak and in some cases one occurs without the corresponding spot required by the symmetry axis. Most of the diffraction planes yielding the adventive spots are represented, on a gnomonic projection perpendicular to the *b*-axis, by poles that lie outside the area in which the poles of the faces measured by G. P. & P. are situated, and therefore cannot be correlated closely with the observed faces. Of the diffraction planes the poles of which lie within this area, a number can be correlated directly with observed complex faces (*C*-faces); several others are related to zones observed by G. P. & P., although they do not correspond to faces actually observed. On the first and second layer-lines (rotation around the *b*-axis) a number of adventive spots of weak intensity are present from diffraction planes parallel to complex faces (*C*-faces) observed by G. P. & P., and on the second layer-line (rotation around the *b*-axis) there are also present a few weak adventive spots representing diffraction planes the poles of which lie in complex zones observed by

[44] W. SCHNEIDER, Zeit. f. Krist., 69: 41–48. 1928.

G. P. & P., and midway between poles of faces observed by them. The remaining adventive spots that represent diffraction planes the poles of which occur in the area in which the poles of the observed faces lie, cannot be correlated with the observed faces in any simple or direct way. Smith[45] and G. P. & P.[46] found that in their composite gnomonic projections of the crystal faces of calaverite, many of the zone-lines passing through the poles of complex faces include a considerable number of face-poles; they also found that these poles of complex faces are spaced at equal intervals along a given zone-line, or, in some cases, at rational sub-multiples or multiples of the unit interval. Since each layer of the reciprocal lattice can be regarded as a gnomonic projection of all the crystal planes having one Miller index in common, the question arose whether or not lines could be drawn through the poles of the adventive diffraction planes (in a layer of the reciprocal lattice perpendicular to the *b*-axis) in a manner similar to the zone-lines through the poles of the complex faces. It was found that if lines are drawn through the poles of the adventive diffraction planes in such a layer of the reciprocal lattice (one perpendicular to the *b*-axis), very few lines contain more than two poles of adventive diffraction planes. Of course, if all the reciprocal lattice-layers were combined in a single gnomonic projection, the number of poles of adventive diffraction planes lying along some lines would be increased. However, there is a striking contrast between the results of the morphological and röntgenographic investigations in that, whereas in the composite gnomonic projection of the external faces of calaverite only 12 simple *S*-forms are represented, on our Weissenberg negatives taken by means of Cu-radiation with the crystal rotating around the *b*-axis there are represented structural planes corresponding to 66 potential as well as to all the 12 observed morphological simple *S*-forms except *A*(304) and *b*(010). Of these remaining two observed morphological simple *S*-forms the plane 010 yields diffraction effects on other films; the plane 304 cannot yield a first order diffraction line in the space-groups possible for calaverite, and the spacing of this plane is too small for the second order diffraction line to be theoretically possible with Cu-radiation. At the same time the great majority of the *C*-forms (complex calaverite forms), which predominate in the composite gnomonic projection of the external faces as yet have not been found represented among the adventive diffraction planes.

[45] Op. cit., p. 136, also Fig. 3 on p. 137.
[46] Op. cit., pp. 21–22, also Plate III.

The presence of the adventive diffraction spots on the Weissenberg photographs of calaverite crystals of course raised the question whether the crystals might not be aggregates of differently oriented grains of calaverite or mixtures of calaverite with some other mineral. The analysis of the Weissenberg photographs has proved, however, that the crystals cannot be explained as aggregates of differently oriented grains of calaverite; this analysis has shown that each of our apparently single crystals contains only one structural lattice, and that the adventive diffraction spots from such a crystal cannot be referred to subsidiary grains repeating the same lattice in different orientations, since the spacings of some of the diffraction planes producing the adventive diffraction spots are different from the spacings of any planes in the calaverite structural lattice.[47]

MICROSCOPIC EXAMINATION OF POLISHED SURFACES OF CALAVERITE

In an attempt to find out whether or not the calaverite crystals contain particles of some other mineral, we have examined polished surfaces of several of our crystals under the reflecting microscope.[48] Polished surfaces were made parallel and perpendicular to the *b*-axis and were examined with and without crossed nicols at medium (240×)[49] and high (900×)[50] magnifications; no inclusions or impurities could be found, and no twinning lamellae, or any other indication that the crystals are not in reality single crystals.[51] We have not excluded the possibility, of course, that a second phase or mineral may be present in a very finely dispersed condition in the calaverite, the individual particles of the disperse phase not being visible with the polarizing microscope, but the presence of such a disperse phase does not appear probable.

[47] For the purpose of indexing the lines of our powder photographs of calaverite we have computed the spacings of all planes in the structural lattice that are greater than 1.000 Å, and have arranged the results in a table of decreasing spacings. The spacings of several of the diffraction planes producing the adventive spots were computed from measurements on the Weissenberg negatives and compared with the spacings in this table.

[48] The authors are greatly indebted to Prof. L. C. Graton and Dr. E. B. Dane, Jr., of Harvard University, and to Dr. J. W. Greig of the Geophysical Laboratory for their kind assistance in the preparation and examination of the polished surfaces, and for the use of their polishing equipment and reflecting microscopes.

[49] The medium power objective was a Leitz 8 millimeter dry apochromat.

[50] The high power objective was a Zeiss 2 millimeter oil-immersion apochromat.

[51] One crystal of calaverite from Cripple Creek, kindly supplied by Prof. Charles Palache and Dr. M. A. Peacock of Harvard University, showed two differently oriented parts when a fragment of it was ground and polished and examined under the reflecting microscope; the differently oriented parts were easily detected between crossed nicols.

HYPOTHESES SUGGESTED BY PREVIOUS AUTHORS TO EXPLAIN THE PECULIARITIES OF CALAVERITE

Although the morphological observations of Smith and of G. P. & P. are in close agreement, the physical interpretation suggested by Smith was not accepted by G. P. & P. Smith concluded that the coexistence, at any point of a crystal, of the five morphological lattices constructed by him from his goniometric measurements would imply heterogeneity of the crystal. Thus he[52] wrote: "The only hypothesis remaining appears to be the existence of a minute skeletal structure of some kind—an infinitesimal framework composed of material with an arrangement according to one lattice intercalated with material with an arrangement according to another lattice. Since the lattices, while not congruent with one another, have a zone in common, i.e. the rows parallel to its edge equidistant, or at least congruent, in parallel planes, and have other relations, . . . interaction at some of the boundaries separating the differently constituted sections would seem to be indicated. This hypothesis is in harmony with the suggestion made above as to the origin of the brittleness of the crystals.[53] The frequent occurrence of pits on the faces, and the existence of skeletal and hollow crystals, suggest breaks in continuity of the homogeneous arrangement." G. P. & P. also recognized the apparent coexistence of several morphological lattices, but in view of the close relationships found between these lattices, they concluded that all the lattices pertain to a *single* crystal. According to the interpretation of G. P. & P. the faces of a single crystal of calaverite cannot all be given simple indices; however, even the assumption of Smith that the crystals are really finely heterogeneous and contain several lattices, does not result in the assignment of simple indices to all of the important faces. Moreover, Smith himself recognized that the crystals could well be interpreted as monoclinic single crystals, or in some cases as simple monoclinic twins, except for the fact that such an interpretation would result in complex indices for most of the common forms. Thus as Smith[54] well stated: "We have a morphological development of the face which is completely in accord

[52] G. F. HERBERT SMITH, op. cit., p. 143.

[53] Smith's suggestion as to the origin of the brittleness of calaverite was as follows (op. cit., p. 143): "If the crystals are composed of two or more individuals so intimately intermixed that the separation is not visible to our perceptions, and if each individual has a cleavage in corresponding but not parallel directions, the brittleness would be explained: and further, if the constituent individuals at particular points are sufficiently small, the fractured surfaces would not give distinct and definite reflections; the surfaces in fact give a blur of light."

[54] Op. cit., p. 141.

with monoclinic symmetry. This view of the symmetry is confirmed by the frequent occurrence of a faces of the form *Y* [the clinopinacoid, *b*, according to Goldschmidt, Palache, and Peacock.—G. T. and C. J. K.], which invariably gives a single distinct image, and not one blurred or double, such as would be expected did it really belong to two or more separate individuals. The faces also occur in positions similar to those of their poles on the sphere of projection, and there are none of the markings or re-entrant angles (beyond those in the prism zone)[55] which usually accompany twinning, however much concealed. Later on, when we proceed to consider twin crystals, we shall find that the planes of twinning except that of the fourth, a doubtful type, have simpler indices on the hypothesis of monoclinic symmetry." However, the fact that this interpretation would necessitate the assignment of complex indices to most of the common and best developed faces, caused Smith to explore the possibilities that might lie in the hypothesis of heterogeneity.

The hypothesis that calaverite crystals may be heterogeneous on a very fine scale—we now know that the subsidiary particles, if present, must be very small and were not visible with the microscope—cannot be entirely laid aside as yet, but we can now be sure that each of the apparently single calaverite crystals has one main individual the structural lattice of which is analogous to the morphological lattice first found by Penfield and Ford, and retained by G. P. & P. as the fundamental morphological lattice of calaverite (the *S*-lattice).

Recently Borchert[56] concluded from studies of polished surfaces of calaverite and krennerite with the reflecting microscope, that calaverite is the high temperature modification and krennerite the low temperature modification of the same compound. He observed lamellae in some crystals of calaverite from Cripple Creek, Colorado, which were rendered easily visible by the use of crossed nicols and etching reagents, such as aqua regia.[57] These lamellae were interpreted by Borchert as having been formed during a polymorphic inversion. He regards the faceted, apparently single, crystals of calaverite as paramorphs having the internal structure of krennerite (Borchert refers to the faceted, apparently single, crystals of calaverite as "Original-α-Calaverit" and to krennerite as "primärer β-Cala-

[55] Smith states elsewhere in the same article (p. 122) that the re-entrant angles in the prism zone are due to its oscillatory and striated character.

[56] H. BORCHERT, Neues Jahrbuch für Mineralogie, Geologie und Paläontologie, Beilage-Band 69, Abt. A: 466–472. 1935.

[57] H. BORCHERT, Neues Jahrbuch für Mineralogie, Geologie und Paläontologie, Beilage-Band 61, Abt. A: 106–116. 1930.

verit"). Borchert[58] also concluded that: "Die Frage der Kristallsysteme [of krennerite and calaverite] muss einstweilen offen gelassen werden. Dagegen kann doch festgestellt werden, dass die Untersuchungen von V. Goldschmidt, Ch. Palache und M. Peacock sich gut mit der naheliegenden Auffassung in Einklang bringen lassen, dass sich die singulären Knoten, die ein sylvanitähnliches Punktsystem mit einem Hauptknoten überlagern, aus der stattgehabten Paramorphose erklären und dass das Gesetz der rationalen Indizes als allgemeiner Ausdruck regelmässigen Gitterbaues keine Einbusse zu erleiden braucht."

It has been proved, however, by our work that Borchert's hypotheses are quite untenable. Our faceted, apparently single, crystals of calaverite from Cripple Creek, Colorado, have undergone no polymorphic inversion and are not paramorphs. We have proved that the structural axes of our calaverite crystals coincide in direction with their morphological axes, also that the axial ratio calculated from the dimensions of their structural unit cell agrees within the limit of error with the axial ratio of calaverite determined morphologically by G. P. & P. Moreover, no lamellae have been found in our crystals, although a careful search was made for evidence of heterogeneity in oriented polished surfaces with and without crossed nicols and with medium and high power objectives, also by etching the polished surfaces with aqua regia and concentrated nitric acid. It is quite possible, of course, that some calaverite crystals contain lamellae such as those described by Borchert; however, Borchert's hypothesis is that all calaverite (Original-α-Calaverit) crystals have passed through a polymorphic inversion and he states that the lamellae produced by this inversion are easily discernible optically.[59] The correlation of the röntgenographic analysis of our calaverite crystals with the measure-

[58] Neues Jahrbuch für Mineralogie, Geologie und Paläontologie, Beilage-Band 69, Abt. A: 469. 1935.

[59] Borchert writes (Neues Jahrbuch für Mineralogie, Geologie und Paläontologie, Beilage-Band 69, Abt. A: 468. 1935): "Entscheidend für α-Calaverit sind die wohl nie ganz fehlenden Anzeichen für die stattgehabte Umkristallisation," and on the same page, "Die leichte oder schwere Erkennbarkeit der Lamellen bildet neben ihrer äusseren Form und Anordnung einen weiteren charakteristischen Unterschied zwischen Original-α-Calaverit und primärem β-Calaverit. Die Zerfallslamellen sind optisch leicht sichtbar, während die Verswilligung beim β-Calaverit offenbar gewöhnlich nach einem Gesetz erfolgt derart, dass die optische Orientierung der Lamellen nur sehr wenig verschieden ist." On page 472 of the same article he adds, "Die Lagerstätten von Cripple Creek und von Săcărâmb (Nagyag) führen sowohl α- wie auch β-Calaverit; genauer, es kommt neben dem lamellaren Calaverit, der ursprünglich als α-Modifikation entstanden ist, auch der primär rhombische vor. (Ob die Einordnung in die verschiedenen Kristallsysteme zutreffend ist oder nicht, spielt dabei für die Auswertung der allotropen Umwandlungen keine Rolle.) Im Cripple Creek-Distrikt herrscht offenbar der lamellare Calaverit vor, der ja in Form von Einzelkristallen von diesem Fundpunkt in allen grösseren Sammlungen vertreten ist."

ments made on the same crystals with the two-circle reflection goniometer proved that each crystal, apparently single as judged by the development of its external faces, contains but one structural lattice. We have also shown that, if the adventive diffraction spots are due to the presence of particles of a disperse phase, then, from the distribution and intensities of the adventive diffraction spots and from our microscopical studies, these particles must be individually very small and must constitute altogether only a minor part of the crystals; certainly even if such particles are present they afford no reason to suppose that the crystal has passed through a polymorphic inversion, but rather must constitute some unusual type of intergrowth.

Finally Borchert's hypothesis that calaverite (Original-α-Calaverit) is identical structurally with krennerite (primärer β-Calaverit) as a consequence of a polymorphic inversion having occurred in the calaverite (Original-α-Calaverit) has also been disproved. Well developed, faceted crystals[60] of krennerite previously measured on the two-circle reflection goniometer were investigated on the Weissenberg X-ray goniometer by the equi-inclination method. Although the röntgenographic analysis has shown that the unit length of one axis of krennerite (the *c*-axis of vom Rath) corresponds quite closely with the unit length of the *b*-axis of calaverite, the other axes of the two minerals are quite different. The volume of the unit cell of krennerite is approximately 4 times the volume of the unit cell of calaverite.[61] The powder photographs of the two minerals are very similar, and the rotation photograph of krennerite taken around the *c*-axis of vom Rath bears a rather close resemblance to the rotation photograph of calaverite taken around the *b*-axis; in addition to the similarity between the spacings of the layer-lines there is a close similarity in the spacings and intensities of some, although by no means all, of the spots along the layer-lines. However, the Weissenberg photographs of corresponding layer-lines of these rotation photographs of the two minerals are very different indeed, and leave no doubt that the structures of calaverite and krennerite are not the same.

A new type of crystal intergrowth has been suggested by Donnay[62] as a possible explanation of the morphological peculiarities of calaverite. He observed a geometrical relationship previously unrecognized in the morphology of calaverite, namely, that the gnomonic poles of the faces (complex faces as well as simple *S*-faces) are, with few ex-

[60] Kindly supplied by Professor Charles Palache and Dr. M. A. Peacock of Harvard University, to whom the authors wish to express their appreciation.
[61] Cf. G. TUNELL and C. J. KSANDA, this JOURNAL, **26**: 507–509. 1936.
[62] Op. cit.

ceptions, distributed in adjacent parallel belts of equal width, that can be alternately referred to two, non-interpenetrating, plane nets. This observation led him to the hypothesis that the apparently single crystals of calaverite each consist of two intergrown triclinic lattices mutually oriented according to a definite law.

A principal difficulty in correlating our röntgenographic results with Donnay's hypothesis that the apparently single crystals of calaverite consist of an intergrowth of two triclinic lattices is that we have not been able to obtain any diffraction effects from the planes taken by Donnay as pinacoids in his two triclinic lattices except the plane *E*, the front pinacoid in both of his lattices. The plane *E* is a plane of our structural lattice having the symbol 801; a diffraction effect is obtained from this plane, but the spacing of this plane is small and it is not a principal plane of the structural lattice. A second difficulty is that, for the reasons stated in the preceding pages, we find it impossible to combine the points in reciprocal space corresponding to the adventive diffraction spots with the points in reciprocal space corresponding to the monoclinic structural lattice to form one or more triclinic reciprocal lattices.

CONCLUSION

The complex faces characteristically present on crystals of calaverite have been found to be related, at least in part, to certain adventive diffraction spots in the X-ray spectra of these crystals. Along with the complex faces there are commonly present a number of simple faces (*S*-faces). We have previously described the crystal structure of calaverite, which has the symmetry of the monoclinic system, and pointed out that the structural elements are analogous to the fundamental morphological elements of Goldschmidt, Palache, and Peacock (their *S*-elements). The structural lattice is thus closely related to the simple crystal faces designated by Goldschmidt, Palache, and Peacock the *S*-faces. A complete explanation has not yet been found for the complex faces or the adventive diffraction spots. It appears probable that the solution of the problem presented by these unusual features will not be found in the geometrical arrangement of the 2 gold and 4 tellurium atoms in the structural unit cell of calaverite, but rather in some type of subsidiary phenomenon in the crystals.

Oriented polished surfaces of calaverite crystals were examined by us with reflected light. No inclusions, or twinning, or any kind of departure from perfect homogeneity were visible under the polarizing microscope.

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PALEONTOLOGY.—*A new crassatellid from the Waccamaw formation of North and South Carolina and the Caloosahatchee marl of Florida.*[1] F. STEARNS MACNEIL, U. S. Geological Survey. (Communicated by JOHN B. REESIDE, Jr.)

While attempting to identify a crassatellid from the Intracostal Waterway, 3 miles west-southwest of Little River, S. C., the writer found that specimens from the Pliocene of the Carolinas, previously identified as *Crassatellites gibbesii* (Tuomey and Holmes), include, in addition to that species, another well defined species which is described below as new.

As has been pointed out by Lamy, Iredale, and Stewart, the name "*Crassatellites*" Krueger is based on rather uncertain grounds. Its acceptance depends on whether *Crassatella* Lamarck is a synonym of *Mactra*, and, if so, whether Krueger's genera are valid or are to be interpreted as a special nomenclature, i.e. the addition of *ites* for a fossil form. At any rate, "*Crassatellites*," if valid, is an Eocene shell and not confusable with American Miocene to Recent crassatellids.

Stewart proposed the expansion of the Australian genus *Eucrassatella* Iredale to include Miocene to Recent American forms having smooth internal margins and large ligamental cavities, and described the subgenus *Hybolophus* for the opisthogyrate *Crassatella gibbosa* Sowerby from the west coast. *Eucrassatella* agrees more closely with the American forms in shape and hinge characters, but does not have the flat, often turned-over umbos characteristic of the American forms. *Hybolophus gibbosa* has flat, turned-over umbos, but is so extreme in other ways that it appears to be at least subgenerically removed from other American species. It may be that the American species are in need of a new generic name but that could be given conscientiously only after a systematic study of all Tertiary crassatellids had been made and then, probably, on phylogenetic grounds. For the present the American forms will be referred to the genus *Eucrassatella*.

[1] Published by permission of the Director of the U. S. Geological Survey. Received October 12, 1936.

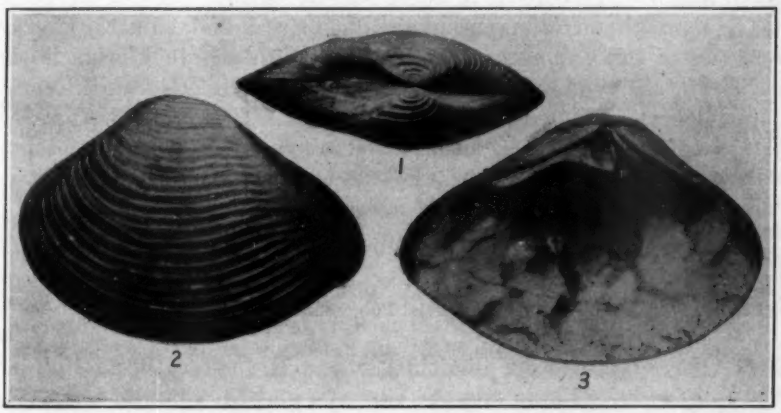
Eucrassatella mansfieldi MacNeil, n. sp.

Shell subtrigonal, moderately inflated, anterior rounded, posterior more produced and sub-angulate; umbonal ridge bounded anteriorly by a well-developed sulcus; beaks just anterior of center and slightly opisthogyrate, flattened and horizontal or slightly turned over; sculpture consisting of coarse, concentric undulations, about 35–40 in number in full grown adults, which, until the shell is half grown, terminate at the umbonal ridge, but in adults terminate in the sulcus.

Dimensions of holotype: Length 61 mm, height 42.5 mm, convexity 10 mm. Largest paratype: Length 77 mm, height 56.5 mm, convexity 14 mm.

Holotype: U. S. Nat. Mus. Cat. no. 495195. Paratypes: 495196.

Type locality: Highest bed at Neill's Eddy Landing, right bank of Cape Fear River, 5 miles northeast of Acme, Columbus County, N. C., U. S. G. S. Sta. 4276.



Figs. 1–3.—*Eucrassatella mansfieldi* MacNeil, n. sp., highest bed at Neill's Eddy Landing, right bank of Cape Fear River, 5 mi. northeast of Acme, Columbus Co., N. C., U. S. G. S. Sta. no. 4276. 1.—Paratype, U. S. Nat. Mus. Cat. no. 495196. 2–3.—Holotype, U. S. Nat. Mus. Cat. no. 495195.

Other occurrences in the Carolinas: Upper bed on the north shore of Lake Waccamaw, N. C.; Acme, N. C.; Cronly, N. C.; Intracostal Waterway, 3 miles west-southwest of Little River, S. C.

E. mansfieldi differs from *E. gibbesii* (Tuomey and Holmes) in being relatively more elongate and less high, and in having coarser and fewer ribs. Specimens of *E. mansfieldi* and *E. gibbesii* of about equal size have about 31 and 55 ribs respectively. The flattened area of the beaks is larger in *E. mansfieldi*.

This species and *E. gibbesii* were both collected along the spoil bank of the Intracostal Waterway but with a matrix of different texture adhering and may be from different beds. *E. mansfieldi* is the only species collected at the localities in North Carolina listed above.

E. gibbesii is also present in the collections in the U. S. National Museum from the following localities: Tilly's Lake, Waccamaw River, S. C.; Wilmington, N. C.; 2 miles north of Padgett, Onslow County, N. C.

Neither species has been collected from the Walker's Bluff locality on the Cape Fear River, 18 miles east-southeast of Elizabethtown, N. C., but two eroded valves of *E. undulatus* (Say) which may be reworked from the Miocene are in the collection from there.

One small valve probably referable to *E. mansfieldi* is in the collection from the Caloosahatchee marl of south western Florida, from near the head of Prairie Creek, a tributary of Shell Creek which flows into Charlotte Harbor, U. S. G. S. Sta. no. 3300.

The more abundant species at the Shell Creek and Alligator Creek localities of the Caloosahatchee marl of southwestern Florida is of the *E. gibbesii* type but is more like Recent specimens from Florida than Pliocene specimens from North Carolina. It is probable that *E. floridanus* (Dall) which he later placed in synonymy with *E. gibbesii* is the valid name for the Recent species and that the Shell Creek and Alligator Creek forms should be referred to it.

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BOTANY.—Tetracoccus ilicifolius, *a new shrub from Death Valley, California.*[1] FREDERICK V. COVILLE and M. FRENCH GILMAN.

In exploring new canyons in Death Valley, California, during the last three seasons, in connection with his work for the National Park Service, Mr. Gilman has found nearly 50 species of plants hitherto unknown in that desert area. In May, 1936, in the large canyon on the west side of the Grapevine Mountains, next north of Titus Canyon, he discovered a new shrub seemingly unrelated to any other plant of the region. The hollylike form of the evergreen leaves, an inch or less in length, lead to the suggestion of hollybush as the common name of this shrub.

Further features of the plant are that the capsule has the unusual number of 4 cells, each cell containing 2 ovules, that the leaves are opposite, and that the plant is dioecious. These characteristics, together with the absence of a corolla, indicated a relationship with *Tetracoccus dioicus*. That plant is the only species of the genus *Tetra-*

[1] Received September 3, 1936.

coccus, of the family Euphorbiaceae, subfamily Phyllanthoideae, and is very rare, being known only from a few localities in northern Lower California, and in the vicinity of San Diego, California. Not only in technical characteristics do the two plants resemble each other, but also in such intimate characteristics as leaf texture and the peculiar hairs of the pubescence. The Death Valley plant is here described as a new species of *Tetracoccus*.

Tetracoccus ilicifolius, sp. nov.

Frutex dioicus, cortice griseo; folia opposita, uncialia, ovato-lanceolata, coriacea, dentata, iliciformia, viridia, sempervirentia, juventate levissime stramineo-villosa, anno altero glabra, petiolo 1–2 mm longo, stipulis nullis; inflorescentia lateralis bractearum caducarum axillis ad ramorum novorum basim; flores apetali; masculi axe aut ramulis brevibus inflorescentiae subuncialis fasciculati, 2–3 mm longi, sepalis et staminibus 7–9; feminei solitarii, pedunculo bibracteolato; sepala 8, in fructu immaturo 3–5 mm longa, herbacea, appressa, acuminata, parce stramineo-tomentosa, marginibus imbricatis, 4 exteriora lanceolata vel ovata, 4 interiora ad basim angustiora; capsulae immaturae oblongo-orbiculares, stramineo-tomentosae, 7–8 mm longae, 4-loculares, ovulis in loculo quoque 2; styli 4, 2–3 mm longi, ad apicem latiores, apice interdum incurvati, in apicem capsulae immaturae divaricate appressi.

Plant a dioecious shrub, 0.3 to 1.3 meters in height; twigs of the season purplish, sparingly villous with pale brown, flexuous hairs, the twigs of the preceding season purplish and smooth, those of earlier seasons gray; leaves opposite, evergreen, in the second year usually deep green above and paler beneath, 2.5 to 1.5 cm in length or sometimes even smaller, thick, coriaceous, ovate-lanceolate to ovate, with as many as six teeth on each margin, resembling the leaves of *Ilex aquifolium* and *Ilex opaca*, broadly acute at the apex, rounded at the base, pinnately veined, sparingly villous with pale brownish hairs on both surfaces when young, smooth in the second year, on stout petioles 1 to 2 mm long, without stipules; flowers apetalous, borne toward the leafless base of new twigs of the season, on peduncles from the axils of caducous bracts; male flowers numerous, in clusters less than 2 cm long, fasciculate on the main axis or on short lateral branches, with 7 to 9 lanceolate smooth sepals 1 mm or less in length, and 7 to 9 stamens 2 to 3 mm long, the filaments slender and smooth, the anthers about 0.7 mm long, nearly as broad, 2-celled, extrorse, dehiscing longitudinally, attached to the filament at a point a little below the middle of the anther, the main axis of the male inflorescence and its branches sparingly villous with pale brownish, flexuous hairs, some of them gland-tipped; female flowers borne singly and terminally on leafless peduncles, one or two on each flowering twig, the peduncle commonly 6 to 8 mm long, bibracteolate, with pale brownish hairs; sepals 8, on the immature fruit 3 to 5 mm long, green, appressed to the base of the capsule, acuminate, sometimes minutely toothed, tomentose with pale brownish hairs, the margins thinner and somewhat imbricated, the exterior four lanceolate or ovate, the interior four narrower toward the base; disk with a body 3 mm in diameter in the immature fruit, and an additional margin of irregular papilliform teeth, the body of the disk often splitting into four parts; capsule immature in our specimens, tomentose with pale brown-

ish hairs, oblong-orbicular in outline, 7 to 8 mm long, 4-celled, with 2 ovules in each cell, the ovules pendant from a point near the summit of the central axis and about one-third the distance from the top of the cell to the base; styles 4, distinct, 2 to 3 mm long, divaricately appressed against the summit of the immature capsule, wider and flattened above the middle and sometimes incurved at the apex; seeds usually 2 in each cell, the body of the seed 4.5 to 4.7 mm long, about 2.5 mm wide and 1.5 mm thick, smooth and shining, narrowed and rounded at the lower end, narrowed and broadly acute at the upper end, the hilum about a third the distance from the top of the seed body to its lower end, a strophiole, 1.5 mm in length, extending diagonally from a point just above the hilum to and slightly beyond the upper end of the body of the seed; embryo straight and endosperm thin, the two cotyledons flat and thin, 2 mm wide by 3 mm long, the radicle extending beyond the hilum into the acute apex of the body of the seed.

Type specimen in the United States National Herbarium, no. 1,650,292, collected in Death Valley, California, at an altitude of about 2,000 feet, in the large canyon north of Titus Canyon, on the west slope of the Grapevine Mountains, May 30, 1936, by M. French Gilman (no. 2180). An additional specimen with the same data is Gilman 2181.

The bushes grew chiefly in crevices in the rock wall of the canyon, which at this point consists of rhyolite. Only eleven plants were found on the first visit, May 30, 1936. On a later visit, August 2, 1936, to get mature seeds if practicable, Mr. Gilman, after very careful search, located four additional plants, one of them half-dead.

The day selected for this second visit was expected to be cool, but the official Weather Bureau maximum shade temperature at Furnace Creek Ranch, in the bottom of Death Valley, known in the Weather Bureau records as Greenland Ranch, was 125° Fahrenheit.

Of the fifteen known plants of this species only two have been definitely ascertained to be pistillate, and only one of the two matured its fruit in 1936.

The individual bushes vary in height from a foot to four and a half feet. They grow in cracks in the rock, and as is usual with shrubs in such a situation, they have an enlarged base from which spring the stems. These are ordinarily three-fourths of an inch to an inch in diameter at the base, in the largest plant reaching about 2 inches. The color of the bark is light gray. The bushes are not dense, like many desert shrubs, but of an open growth and irregular shape. Their breadth is greater than their height. A bush 3 feet high was 5 feet across, and the largest bush, 4.5 feet high, was 8 feet across. This largest bush grew in a large vertical crack that provided it with more soil than the other plants, and several cross cracks collected for it an unusual amount of moisture from the few and scant rains in Death Valley.

Tetracoccus was proposed in a manuscript note by George Engelmann as a new genus name for some specimens with immature fruit collected by C. C. Parry in February, 1883, near Table Mountain, Lower California. Dr. Engelmann, whose death occurred February 4, 1884, did not himself publish the description, but additional specimens with staminate flowers and mature fruit having been collected by C. R. Orcutt September 24, 1884, on hills

near Santo Tomás, Lower California, a description of the genus was published by Sereno Watson on February 21, 1885.[2] Dr. Watson said that the examination of the Parry specimens of *Tetracoccus* probably was Dr. Engelmann's last botanical work. To the generic description Dr. Watson added a description of the species under the name *Tetracoccus engelmanni*.[3] However, a description of the genus had been published a few days earlier,[4] by Parry, who named the species *Tetracoccus dioicus*.[5] Both Parry's and Watson's descriptions were based on the same collections.

In 1906 T. S. Brandegee described a *Tetracoccus hallii*[6] from the Colorado Desert, southeastern California. This plant, however, has a 3 celled ovary, and in neither habit nor pubescence does it resemble *Tetracoccus dioicus*. In 1923 I. M. Johnston took *hallii* out of *Tetracoccus* and placed it, along with two other species previously referred to the genus *Securinega*, in a new genus, *Halliophytum*.[7] Prior to the discovery of the present new species from Death Valley, *Tetracoccus* remained, therefore, a monotypic genus containing only the rare and local species, *T. dioicus*, discovered half a century ago.

In *Tetracoccus dioicus* the leaves are linear and entire, with a maximum length of about 30 mm and a maximum width of about 5 mm, and with no lateral veins; the clusters of male flowers are in the axils of leaves on the new growth, a final cluster often terminating the twig; and the young twigs and leaves are devoid of pubescence.

The lack of fully mature fruit and seeds of the new species makes impossible a wholly satisfactory comparison of these parts. In a boiled capsule of *T. ilicifolius* collected on May 30 the strophiole on an immature seed is 2 mm long and 1 mm thick at the upper end (the end of the strophiole away from the hilum), the body of the immature seed on which this strophiole is borne being 4.5 mm long when wet and soft. In one, and presumably all, of the eight fruits collected on August 2, 1936 (Gilman 2235), and about two months nearer maturity than those first collected, two seeds are maturing in each of the capsule cells. The seeds are buff-colored at this stage, about 2.5 mm wide, 1.5 mm thick, and 4.5 to 4.7 mm long, the strophiole amber-colored and translucent, and in its dried condition 1.5 mm. long. In *Tetracoccus dioicus* a single seed, usually, matures in each cell. Its width and thickness are both about 2.5 to 2.8 mm, its length about 4.7 to nearly 6 mm, and its color at full maturity dark brown. The strophiole is about 1 mm long and it extends not quite to the apex of the seed. Although the capsules of *ilicifolius* collected August 2 are not sufficiently mature to have split open naturally, their bony inner wall is half a millimeter thick. On being opened

[2] Proc. Amer. Acad. 20: 372. 1885.

[3] Op cit. 373.

[4] On February 5, 1885, according to William Trelease and Asa Gray, *The botanical works of the late George Engelmann*, page 449, 1887.

[5] West Amer. Scientist 1: 13. 1885.

[6] Zoe 5: 229. 1906.

[7] Contr. Gray Herb. n. ser. 68: 88. 1923.

the capsules show a tendency to split down the middle of each cell, each bony half-cell tending also to separate from the corresponding part of the neighboring cell, just as in *Tetracoccus dioicus*.

All botanists who have described the seeds of *Tetracoccus dioicus* state that only a single seed matures from the two ovules in each cell. However, excellent specimens of that species collected July 30, 1936, in San Diego County, California, by Frank F. Gander, Curator of Botany in the Natural History Museum, San Diego, have occasional cells in which both the ovules have developed into seeds, each seed containing an endosperm and a full-sized embryo. When two seeds ripen in a single cell they are much thinner than the single seeds of this species described in the preceding paragraph.

When examined in Washington on November 19, 1936, nearly four months after it was taken from the bush and pressed for the herbarium, Mr. Gander's specimen bore several capsules that were mature and still intact. During the following night, in the dry atmosphere of a steam-heated building every one of these mature capsules exploded. In exploding, the walls of the four cells broke away from the central axis in eight pieces, and the seeds were thrown clear, some of them to a distance of several feet. The explosion was caused by the release of stresses in the bony inner wall of the capsule.

In *dioicus* the sepals of the female flowers and their peduncles are glabrous, as well as the branches of the inflorescence in the male plants. Near the axils of the bracts of the male flowers are traces of the same sort of pubescence that occurs in *ilicifolius*.

In his original publication on *Tetracoccus* Watson described the female flowers in *T. dioicus* as having 6 or 7 sepals. Parry gave the number as 7 to 9. In specimens of *dioicus* from Santo Tomás, in the National Herbarium, the sepals in the female flowers are sometimes as many as 10, 11, or even 12. In *T. ilicifolius*, in all the immature fruits in which the sepals are in condition to be counted with accuracy, their number is 8. Future examination of new material, however, may show that the number varies.

The ovary of the female flowers in *dioicus* is tomentose with a red tomentum, but the mature capsule is nearly glabrous. The lack of female flowers in our specimens of *ilicifolius* and access to only dried remnants of male flowers still clinging among the leaves make impossible a thorough comparison of the flowers of the two species.

The existence of this new species in a single restricted locality in one of the severest of our deserts, the fewness of the individual plants, and the scarcity of fruit are evidence that the plant is in process of extinction through a still further increase in the aridity of Death Valley, a suggestion supported by similar evidence regarding other plants, such as *Gilmania luteola*.[8]

A 4-celled ovary is rare in the family Euphorbiaceae, but in the sub-family Phyllanthoideae (typified by the genus *Phyllanthus*) genera with 4-celled fruits occur in parts of the world far separated from the continent of North

[8] This JOURNAL 26: 209–13. 1936.

America, such as *Heywoodia* in South Africa.[9] Other characteristics of these genera, however, do not suggest any immediate genetic relationship with *Tetracoccus*, and we may be content to regard this genus as having developed its 4-celled capsule, among its 3-celled relatives, in our own North American arid region.

BOTANY.—*Three new grasses from Indo-China.*[1] JASON R. SWALLEN, Bureau of Plant Industry.

In a small collection of grasses recently received from Professor A. Petelot, of the Ecole de Médicine, Hanoi, Tonkin, collected by him in Indo-China, the following new species were found: *Centotheca uniflora*, *Isachne ascendens*, and *Isachne dioica*.

Centotheca uniflora Swallen, sp. nov.

Perennis; culmi erecti vel geniculati, 80–85 cm longi, glabri; vaginae internodiis breviores, glabrae, marginibus ciliatis; ligula truncata, 0.5 mm longa; laminae planae, 14–21 cm longae, 13–17 mm latae, reticulatae,

Fig. 1.—*Centotheca uniflora*. Glumes and floret (palea and rachilla joint with rudimentary floret displayed) ×10. Type.

glabrae, marginibus scabris; panicula 40–45 cm longa, ramis adscendentibus ad 19 cm longis basi nudis; pedicellii 3–12 mm longi, divergentes; spiculae 3.5–4 mm longae, uniflorae; rachilla producta; glumae subaequales lemma duplo breviores, 3–5 nerves, acutae vel mucronatae, glabrae; lemma 3.5 mm longum, 5–7 nerve, mucronatum, glabrum; palea lemma aequalis.

Perennial; culms erect to geniculate-spreading, 80–85 cm long, glabrous; sheaths a little shorter than the internodes, glabrous, somewhat ciliate toward the summit; ligule 0.5 mm long, membranaceous, truncate; blades

[9] Pax and Hoffmann, Natürlichen Pflanzenfamilien, 2. aufl. 19c: 74. 1931.

[1] Received September 13, 1936.

lanceolate acuminate, conspicuously cross veined, 14–21 cm long, 13–17 mm wide, glabrous on both surfaces, the margins scaberulous; panicle 40–45 cm long, somewhat flexuous or drooping, the subcapillary ascending branches rather distant, naked below, very compound, the lower ones as much as 19

Fig. 2.—A. *Isachne dioica*. Plant ×1; spikelet and upper floret ×10. Type. B. *Isachne ascendens*. Spikelet and pair of florets ×10. Type.

cm long; pedicels spreading, 3–12 mm long; spikelets 3.5–4 mm long, only one floret developed; glumes subequal, acute or mucronate, 3–5 nerved, about half as long as the spikelet; lemma 3.5 mm long, strongly 5–7 nerved, subobtuse, minutely lobed, mucronate, glabrous; palea narrow, 2-keeled, equaling or slightly exceeding the lemma; rachilla joint ⅓ to ½ as long as the palea, sometimes bearing a very small rudimentary floret.

Type in the U. S. National Herbarium no. 1645234, collected in "petite massif de Ang Son, village de Van Huan, Province de Quang Binh," Annam, Indo-China, February 26, 1936, by A. Petelot (no. 5635).

While this species is anomalous in having but a single floret, the character of the plants as a whole agrees with that of *Centotheca*. Two good specimens were available for study, in both of which there was no exception to the one-flowered spikelets. This is sufficient to indicate that the specimens are not abnormal.

Isachne ascendens Swallen, sp. nov.

Annua?; culmi geniculati, adscendentes, ad 30 cm alti, glabri; vaginae internodiis breviores, sparse hispidae, marginibus ciliatis; ligula ciliata, 1 mm longa; laminae planae, firmae, acutae, 3–8 cm longae, 4–8 mm latae, dense pubescentes; panicula 12–14 cm longa, ad 6 cm lata, ramis adscendentibus, basi nudis, inferioribus 6–8 cm longis; spiculae 1.5 mm longae, pedicellibus 2.5–4 mm longis appressis; glumae 1.3 mm longae, obtusae, sparse hispidae vel subglabrae; flosculi simulantes, elliptici, 1.3 mm longi, pubescentes.

Annual?; culms geniculate-ascending, about 30 cm tall, glabrous; sheaths shorter than the internodes, sparsely hispid, the margins ciliate; ligule ciliate, 1 mm long; blades flat, firm, acute, 3–8 cm long, 4–8 mm wide (mostly more than 5 cm long and 5 mm wide), appressed pubescent, densely so beneath; panicle 12–14 cm long, about 6 cm wide, the compound branches ascending, naked at the base, the lower ones 6–8 cm long; spikelets 1.5 mm long, the pedicels appressed, 2.5–4 mm long; florets similar, elliptic, 1.3 mm long, pubescent.

Type in the U. S. National Herbarium no. 1645231, collected in "sentiers dans les savanes herbeuses, Massif du Sang ..... Van Nus, 1600 m, Chapa, Tonkin," Indo-China, July, 1936, by A. Petelot (no. 5617).

This species of *Isachne* is closely related to *I. beneckii* Hack., but differs in having a much stiffer tufted habit, unbranched culms, shorter and broader blades, and appressed spikelets.

Isachne dioica Swallen, sp. nov.

Annua; culmi debiles, decumbentes, ramosi, 10–20 cm longi; vaginae internodiis multo breviores, pilosae vel subglabrae; ligula pilosa 0.5 mm longa; laminae planae, ovatae, 7–16 mm longae; 3–7 mm latae, pilosae, marginibus scabris; paniculae 2–4 cm longae, ramis divergentibus ad 10 mm longis; spiculae 1.8–2 mm longae; glumae 1.3–1.5 mm longae, sparse hispidae, 5-nerves, divergentes; flosculus primus masculus, lemmate membranaceo, 1.8 mm longo, glabro; flosculus secundus femineus, induratus, pubescens, 0.8 longus, plano-convexus.

Annual; culms weak, decumbent-spreading, usually branching, 10–20 cm long; sheaths much shorter than the internodes, pilose or subglabrous; ligule pilose, 0.5 mm long; blades flat, thin, ovate, 7–16 mm long, 3–7 mm wide, pilose, the margins scabrous; panicle 2–4 cm long, the branches ascending to spreading or even reflexed at maturity, as much as 10 mm long, naked below; spikelets 1.8–2 mm long; glumes equal, 1.3–1.5 mm long, divergent, 5-nerved, sparsely hispid; first floret staminate, the lemma membranaceous, 1.8 mm long, glabrous, the stamens 1.5 mm long; second floret pistillate, indurate, plano-convex, 0.8 mm long, brownish, minutely appressed-pubescent with white hairs, borne on a slender white rachilla joint.

Type in the U. S. National Herbarium no. 1645232, collected in "Rizière argilo-calcaire abandonnée, Village de Van Huan, Province de Quang Binh, Annam" Indo-China, February 26, 1936, by A. Petelot (no. 5634).

The large membranaceous staminate floret and the small indurate pistillate floret borne on an exceptionally long rachilla joint are characteristic.

At maturity the glumes and the pistillate floret fall off leaving the staminate floret and the rachilla joint attached to the pedicel.

ZOOLOGY.—*Bryozoa collected in the American Arctic by Captain R. A. Bartlett.*[1] RAYMOND C. OSBURN, Ohio State University. (Communicated by WALDO L. SCHMITT.)

The collections made by Captain Robert A. Bartlett over many years in the Arctic have added much to our knowledge of the occurrence and distribution of the various forms of life. Recently the United States National Museum sent to the writer for determination the Bryozoa from seventeen collecting stations ranging from Hudson and Davis Straits to northwest Greenland. Seven of these were taken by the Norcross-Bartlett Expedition in 1933. The others are scattered collections dated 1926, 1927, 1932 and 1935.

While the Bryozoa are thus apparently incidental collections, they serve to indicate the richness of the fauna in this group in these Arctic waters. A number of the species have not been listed hitherto in the waters west of Greenland and the range of other species is extended.

Perhaps the most characteristic species is the well known *Microporina borealis* (Busk) which occurred at eleven of the stations, in bushy masses reaching a height of four to as much as six inches. It appears to afford a favorite lodging place for many other bryozoan species. In a half pint jar of *M. borealis* taken near Dalrymple Rock, Wolstenholm Sound, N. Greenland, there were found the following 23 species encrusting or attached to the stems:

Gemellaria loricata (L), *Scrupocellaria scabra* (v. Ben.), *Dendrobeania murrayana* var. *fruticosa* (Packard), *Electra crustulenta* var. *arctica* Borg, *Callopora craticula* (Alder), *C. lineata* (L.), *Tegella unicornis* (Fleming), *T. armifera* (Hincks), *Cauloramphus cymbaeformis* (Hincks), *Hippothoa hyalina* (L), *Harmeria scutulata* (Busk), *Myriozoella plana* (Dawson), *Hippodiplosia reticulopunctata* (Hincks), *H. porifera* (Smitt), *Rhamphostomella ovata* (Smitt), *R. costata* Lorenz, *R. plicata* (Smitt), *R. scabra* (Fabr.), *R. spinigera* Lorenz, *Smittina arctica* (Norman), *Costazia ventricosa* (Lorenz), *Lichenopora verrucaria* (Fabr.), and *Crisia* sp.

The localities are listed below and these will be referred to under the various species by the numbers indicated in the list.

[1] Received October 9, 1936.

1. Off Dalrymple Rock, Wolstenholm Sound, N. Greenland, July 22, 1926.
2. Murchison Sound, N. Greenland, August 20, 1926.
3. 66° 30′ N., 80° W., August 10, 1927.
4. Five miles S. of Cape Chalon, N. Greenland, July 27, 1932.
5. Three miles S. of Salisbury I., Hudson Str., 20 Fath., July 25, 1933.
6. W. end of White I., Frozen Str., Fox Channel, August 10, 1933.
7. Hurd Channel, between Bushman I. and Melville Pen., Fox Channel, August 17, 1933.
8. Cove No. 40, N. shore of Lyon Inlet, Melville Pen., Fox Channel, August 24, 1933.
9. Cove No. 50, N. shore of Lyon Inlet, Melville Pen., Fox Channel, August 25, 1933.
10. Entrance to Fury and Hecla Str., 20–30 Fath., Sept. 3, 1933.
11. N. E. entrance to Fury and Hecla Str., Sept. 5, 1933.
12. Hakluyt I., Whale Sound, 77° 26′ N., 72° 30′ W., 68–120 feet, July 30, 1935.
13. E. end of Cobourg I., Baffin Bay, 75° 40′ N., 78° 40′ W., 140–210 feet, August 3, 1935.
14. The same, but 75° 40′ N., 78° 50′ W., 140–210 feet, August 3, 1935.
15. The same, but 75° 40′ N., 78° 53′ W., August 3, 1935.
16. The same, but 75° 40′ N., 78° 55′ W., 150–280 feet, August 3, 1935.
17. S. end of Cobourg I., 75° 40′ N., 78° 58′ W., 40–80 feet, August 4, 1935.

Altogether 60 species occur in these collections, six of which have not previously been reported for this part of the American Arctic. These species are *Crisia cribraria* Stimpson, *Diaperoecia harmeri* Osburn, *Plagioecia* (*Mesenteripora*) *grimaldii* (Jullien and Calvet), *Flustrella corniculata* (Smitt), *Electra crustulenta* var. *arctica* Borg, and *Bugula simpliciformis* Osburn. (For the waters about Greenland and westward see the compiled lists by Osburn, 1919, and 1923, and Nordgaard,—Second Fram Exped., 1906.)

Crisia cribraria Stimpson has been noted only on the American coast from Cape Cod to Labrador; *Diaperoecia harmeri* Osburn from Maine to Nova Scotia, *Flustrella corniculata* (Smitt) is an Arctic species reported from Norway, Spitzbergen and Alaska (the present record fills a large gap in the known distribution). *Bugula simpliciformis* Osburn has been recorded only from Hudson Bay. *Plagioecia grimaldii* (Jullien and Calvet) was described from the Grand Banks of Newfoundland.

Thirty-eight species of the present list were recorded by Nordgaard (1906) in the waters west of Greenland.

In the following list of species taken by Capt. Bartlett, localities are given, for the sake of brevity, in station numbers which may be referred to above.

ENDOPROCTA.—*Barentsia* sp. 15. One young specimen, too small for identification.

CYCLOSTOMATA.—*Crisia cribraria* Stimpson. 6, 9. Well developed colonies, with ovicells. Hitherto this species has been known only from Cape Cod northward to Nova Scotia.

Crisia sp. 9. Probably *C. denticulata* (Lamarck), but without ovicells and too young for positive identification.

Diaperoecia (*Entalophora*) *harmeri* Osburn. 6, 9. This species was described and listed by Osburn (1933, p. 301) from Georges Bank to Nova Scotia. It is not surprising to find it in Arctic waters where it may have been noted previously as a species of Entalophora.

Diplosolen (*Diastopora*) *obelium* (Johnston). 9. Widely distributed in temperate and colder waters.

Oncousoecia (*Diastopora*) *diastoporides* (Norman). 13. Widely distributed in northern waters.

Plagioecia (*Mesenteripora*) *grimaldii* (Jullien and Calvet). 13, 14, 15. In each case a single, stipitate, folded colony with ovicells. The ovicells resemble those of *Tubulipora patina*, but are less transverse than those illustrated. Many of the zooecial tubes are closed, with the closing membrane smooth or perforated or frequently with the small central tubules common in *sarniensis* and some other cyclostomes. The species may prove to be *patina*, but the differences seem to be sufficient to separate it.

Tubulipora flabellaris (Fabricius). 12. Widely distributed in temperate and northern waters.

Lichenopora verrucaria (Fabricius). 4, 6, 9, 11, 12, 13, 14, 17.

CTENOSTOMATA.—*Alcyonidium disciforme* Smitt. 8. The largest representative of this species previously reported was but 17 mm in diameter. Two of three specimens picked up between tides along the north shore of the cove (8) measured respectively 28 and 34 mm in diameter. These disc-like colonial forms were centrally perforate, a condition which seems to have been noticed only once before in scientific literature (Levinsen, Bryozoer fra Kara Havet, 1886, pl. 27, fig. 13). The openings may indicate that this bryozoan at times grows around a stalk of some sort. The only other specimens that I have seen of this species were several of much smaller size, 12 mm in diameter, and without the central holes. They were found attached to stones and algae in Wakeham Bay, Ungava, at very low tide, October, 1927.

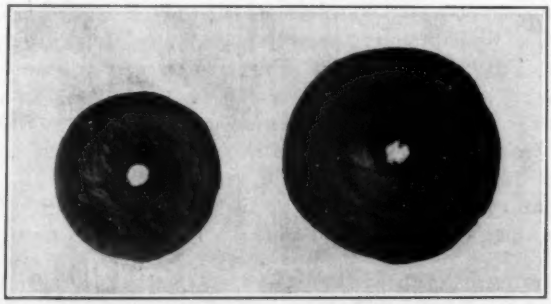

Fig. 1.—*Alcyonidium disciforme*, nat. size. Two specimens of the rarely found perforate form. The largest previously known specimen was about two-thirds of the size of the smaller one figured here.

Bowerbankia gracilis Leidy. 2. *B. caudata* (Hincks) and *Farella arctica* Busk, both recorded for Artic waters, are probably synonymous.

Flustrella corniculata (Smitt). 8, 9. Previously known from Norway and Spitzbergen, and from Alaska (*Alcyonidium cervicornis* Robertson). The present record, which is the first from the American Archipelago, fills a large gap in the circumpolar distribution of the species.

CHEILOSTOMATA.—*Gemellaria loricata* (Linnaeus). 1, 4, 9.

Membranipora serullata (Busk). 9, 10, 13, 14. Rather abundant at these stations and occurring in both the encrusting, unilaminar, and the flustrine condition as narrow irregular fronds.

Electra crustulenta (Pallas) var. *arctica* Borg. 1, 12, on shell and pebbles. Dr. Folke Borg (1931) has made a careful analysis of several much confused species of the old genus *Membranipora,—membranacea, reticulum, lacroixii, crustulenta, mülleri, monostachys* and *catenularia.* It is very difficult to state the distribution of these species, due to misidentification by even the best workers of the past. It is certain however, that the present species is Borg's var. *arctica,* since it has the well calcified operculum.

Callopora craticula (Alder). 1, 6.

Callopora lineata (Linnaeus). 1, 6, 12.

Callopora spitzbergensis (Bidenkap). 4, 12.

Callopora spathulifera (Smitt). 6, 9, 10.

Tegella arctica (d'Orbigny). 12. Several colonies, one more than an inch across, on a pebble.

Tegella unicornis (Fleming). 1, 4, 6, 12.

Tegella unicornis var. *armifera* (Hincks). 1, 2, 12.

Cauloramphus cymbaeformis (Hincks). 1, 2.

Scrupocellaria scabra (van Beneden). 1, 12, 14, 17.

Tricellaria (*Menipea*) *ternata* (Solander). 3, 8, 9, 13. Mostly of the var. *gracilis* (Smitt).

Tricellaria (*Bugulopsis*) *peachi* (Busk). 4, 10.

Bugula simpliciformis Osburn. 10, 14. There is some doubt about the specimen from Sta. 10 as it lacks both avicularia and ovicells, but the other characters agree well with the type. This species was described (Osburn, 1932, p. 369) from Hudson Bay. All the colonies seen thus far have been small, less than an inch in height, with simple zooecial and zoarial characters.

Dendrobeania murrayana var. *fruticosa* (Packard). 1, 4, 6.

Microporina borealis (Busk). 1, 2, 5, 7, 9, 10, 12, 13, 14, 17. The most abundant and generally distributed species in the collection and harboring most of the other species noted.

Cribrilina annulata (Fabricius). 4, 6, 12.

Hippothoa hyalina (Linnaeus). 1, 2, 4, 6, 9, 10, 12. Encrusting algae, bryozoa and pebbles.

Harmeria scutulata (Busk). 1, 6, 12.

Cylindroporella tubulosa (Norman). 12. Encrusting pebbles.

Posterula sarsi (Smitt). 10, 14. Fine examples of the erect, branching form.

Stomachetosella (*Lepralia*) *producta* (Packard). 12. One small colony on a pebble. As far as I am aware this species has been recorded only once before in Arctic waters (Kluge, 1907, West Greenland).

Hippodiplosia (*Smittina*) *reticulatopunctata* (Hincks). 1.

Hippodiplosia (*Smittina*) *porifera* (Smitt). 1.

Peristomella jacksoni (Waters). 4.

Microporella ciliata var. *arctica* (Norman). 12.

Mucronella connectens (Ridley) = *Escharella indivisa* Levinsen. 6, 10, 12, 14. On algae and pebbles. In describing this species Levinsen (1916, p. 450) appears to have overlooked Ridley's description of *Mucronella ventricosa* var. *connectens* (1881, p. 451). Ridley misinterpreted the large undivided pore chambers, upon which Levinsen especially based his species, but his figures (Pl. XXI, figs. 6, a and b) show this character almost exactly as figured by Levinsen (Pl. XX, figs. 1 and 2). Ridley states that the broad oral denticle has lateral points, while Levinsen indicates it as straight, but my material shows some variation. The other characters are in agreement. I am therefore returning to the use of Ridley's name.

Smittina arctica (Norman). 13.

Rhamphostomella ovata (Smitt). 1, 6, 10.

Rhamphostomella plicata (Smitt). 1.

Rhamphostomella bilaminata (Hincks). 13.

Rhamphostomella scabra (Fabricius). 1.

Rhamphostomella costata Lorenz. 1, 2, 13.

Rhamphostomella spinigera Lorenz. 1.

The presence of six out of the seven arctic forms of *Rhamphostomella* (*R. radiatula* Hincks is the only one lacking) might appear unusual but for the preference which the species of this genus have for attachment to stems such as those of *Microporina borealis*.

Porella acutirostris Smitt. 10, 12, on algae and pebbles.

Porella compressa (Sowerby). 10. Well-developed, branched colonies.

Porella princeps Norman. 14.

Porella struma var. *glaciata* (Waters). 4. Spreading, foliaceous colonies, sometimes of more than one layer.

Cystisella (*Porella*) *saccata* (Busk). 4, 13.

Cheilopora sincera (Smitt). 13, 14. The *Mucronella praelucida* of Hincks must undoubtedly be considered a synonym of *sincera* Smitt, at least as far as records from eastern North America are concerned. The zooecia in specimens from the Gulf of St. Lawrence, Labrador and Hudson Bay are considerably smaller, but in the present material I find, even within the same colony, zooecia which range from the small St. Lawrence type to even larger than the measurements given by Smitt for Spitzbergen and Finmarken specimens. There appear to be no other distinctive characters.

Retepora elongata Smitt. 10, 13, 14, 15.

Lepralliella contigua (Smitt). 13.

Myriozoum subgracile d'Orbigny. 13, 14, 15, 16.

Myriozoella plana (Dawson) = *crustacea* Smitt. 1, 2, 6, 10, 12, 14, 17. Very common, encrusting algae, the stems of *Microporina* and pebbles.

Costazia (*Cellepora*) *ventricosa* (Lorenz). 1, 7, 10, 14.

Costazia (*Cellepora*) *surcularis* (Packard). 10, 13, 14.

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ENTOMOLOGY.—*A note on the occurrence of a pupal abnormality in the flour beetle* Tribolium confusum *Duval.*[1] THOMAS PARK, The Johns Hopkins University. (Communicated by RAYMOND PEARL.)

A rather curious pupal abnormality noted among stock cultures of the flour beetle *Tribolium confusum* seems worthy of brief mention. Two pupae were observed which obviously differed from the normal types in having their thorax and abdomen spirally rotated to the right with a corresponding distortion of the longitudinal axis. These relationships can be seen in Fig. 1 where photo-micrographs of normal and abnormal pupae in dorsal and ventral views are presented. In each illustration black lines have been ruled to correspond with the longitudinal axes. For the normal pupa a single, straight line accurately bisects the individual into right and left sides for head, thorax and abdominal regions. In the abnormal pupa it is necessary to draw four distinct lines to describe the axis from the dorsal view and three from the ventral view. Since nothing is known as to the larval history of these two individuals it is impossible to state if the abnormality was acquired early or late in metamorphosis. Likewise, it is impossible to conclude whether the abnormality is merely some developmental accident or whether a more fundamental basis is involved.

Interest was first attracted to these pupae since, in spite of their structure, they appeared very much alive and gave every indication of developing into imaginal forms. All young *Tribolium* pupae when lightly touched on the mid-ventral surface exhibit a marked flexing movement of the abdomen and it is frequently possible to distinguish between living and dead forms in this manner. This reflex was well developed for the two atypic pupae and suggested that, even though they possessed such an unusual external morphology, certain neuromuscular connections had been established at the time which permitted the described behavior to take place.

[1] Received September 17, 1936.

Of the two twisted pupae, one was a male and the other a female. The latter failed to emerge as an adult *Tribolium* while the former not only emerged but lived about nine weeks. This beetle showed few of the abnormalities characteristic of the pupa: the head and thorax were outwardly entirely normal and only the posterior part of the abdomen exhibited any deviation from type. This deviation consisted of a slight rightward turning of the terminal abdominal segments. The beetle, however, did not prove fertile for, although it was placed with several normal, virgin females, no viable eggs resulted. Whether this was due simply to the inability of the form to copulate, or, whether some more deeply seated mechanism was involved, cannot be said.

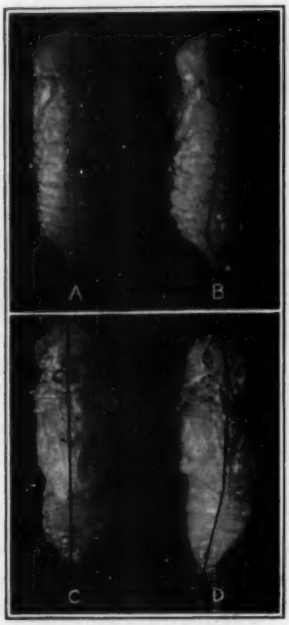

Fig. 1.—Photomicrographs of: A, Dorsal view of normal pupa; B, Dorsal view of abnormal pupa; C, Ventral view of normal pupa; D, Ventral view of abnormal pupa. (Enlarged about 10 times.)

The principal purpose of this note is to place on record a new type of abnormality for *Tribolium*. The author is aware of three other such records. Two of these relate to metathetely or the appearance of wing rudiments in larvae of *Tribolium confusum*. The first report,

that of Chapman (1926), showed that larvae of the flour beetle occasionally develop wing pads when subjected to a "gas" sometimes produced by adult *Tribolium* when present in very dense and disturbed populations. The second report (Nagel, 1934) described the appearance of metathetelous, last instar larvae due to low temperature. The third record (Park) reports the occurrence of a Mendelian recessive gene which causes certain central facets in the eyes of *Tribolium castaneum* Herbst to lack pigment.

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